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10th NTEC/Industry Conference

Naval Training Equipment Center • Orlando, Florida 32813

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A Compilation of papers on a variety of technical and training subjects related to training device technology and training methodology. Representatives include sponsors, users, research, development, and procurement agencies and industry.

The papers in this report were presented at the Tenth NTEC/Industry Conference held 15 - 17 November 1977. The Conference theme, "Resource Conservation Through Simulation," focuses attention on the multiple benefits that →

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accrue through simulation. Simulation provides the technological base for training equipment. Through simulation, it is possible to bring that portion of the real tactical world into the classroom to support training needs. The classroom provides an effective and controlled environment for the individual and team learning experience. The utilization of training equipment results in substantial savings in resources.

The Tenth Conference is part of a continuing program to promote cooperation between Government and industry in the development of effective training equipment, and foster an exchange of new ideas in simulation technology.

FOREWORD

This year the Naval Training Equipment Center is sponsoring the Tenth NTEC/Industry Conference. This conference has become an important event in the continuing dialogue between the various segments of the training and training equipment communities. Representatives include sponsors, users, research, development, and procurement agencies and industry.

This year's theme, "Resource Conservation Through Simulation," focuses attention on the multiple benefits that accrue through simulation. Simulation provides the technological base for all training equipment. Through simulation, it is possible to bring that portion of the real tactical world into the classroom to support training needs. The classroom provides a controlled and effective environment for the individual and team learning experience. The utilization of training equipment results in substantial savings in resources. These savings include the fuel that would be required to operate the various vehicles and the personnel and equipments that would be required to support the training but are not directly involved in the training. Through advancement in simulation technology and training strategies, manning levels of instructors, operators and maintainers have been reduced and even greater reductions are forecast for new training device systems.

The papers published in these proceedings cover a wide spectrum of subjects which have either a direct or indirect relationship to the subject of resource conservation, the conference theme. Each paper, in its own way, discusses some aspect of simulation and its relation to the training process. The information contained in the papers add to the reservoir of information that will be used in the training system development process.

This conference is designed to provide a forum for the effective exchange of information. The advances in training methodology and simulation technology reported here will find their way into development of effective resource training systems.

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Conference General Chairman

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INTRODUCTION TO THE CONFERENCE

G. V. Amico
Director of Engineering
Naval Training Equipment Center

Welcome to the Naval Training Equipment Center's Industry Conference. This year's conference represents a major milestone. It is the tenth conference which the Center has sponsored. The primary conference goal is the same today as it was in 1966; improved communication between government and industry. It is gratifying to note that the number of participants has increased substantially from all sectors of the training equipment community. In 1966, the year of the first conference, 193 attended representing 14 government agencies and 49 private companies. In that year the Center had just completed the FY 1966 training equipment procurement program valued at $71 million. By comparison, the attendance at this year's industry conference is expected to be 600 with 100 government agencies and 150 industries being represented. The Center's research, development, acquisition, and modification program for FY 1977 totaled over $270 million.

The training device program has experienced substantial growth during the past 10 years. The rate of growth has accelerated in the most recent years and the forecasts are for a continuation of this trend. The selection of the theme for this year's conference, "Resource Conservation Through Simulation," focuses attention on the important role that simulation has played and will continue to play in resource conservation policy and plans. Although the oil embargo of 1973 focused major attention on the conservation of fossil fuels through increased use of simulators or trainers, that is not the only area that deserves our attention. The training devices themselves have increased in complexity to support the complex operational systems in the inventory. Advances in technology have enabled inclusion of many training tasks not previously possible. The long established role of trainers for familiarization, normal, and emergency procedural training has been expanded to include increased operator and team training for the tactical employment of the weapon system. The single greatest advance in this area has been the inclusion of visual tasks which have been made possible by both government and industry research in this high-risk and technically complex area.

I would like to cover three major areas where simulation technology contributes to resource conservation. The first and most obvious area involves the use of simulation technology in individual, team and multiplatform tactical training systems to conserve energy, personnel, weapons, and supplies. The second area relates to the optimization of trainer system design for a stated set of functional requirements that would minimize space and power requirements. The third conservation area relates to the application of advanced simulation technology to reduce personnel manning requirements for training systems.

Let us look in somewhat greater detail at the role that simulation plays in the area of operator, team, and multiplatform tactical training systems. The chess-like war gaming, or Kriegspiel introduced by Reisswitz in 1824, was used to develop and evaluate strategy and tactics. Today, the Army's Combat Arms Tactical Training System, a real-time, digitally controlled device, is used for staff training at the battalion level. A typical exercise simulates a tactical problem involving approximately 6,000 men and 1,100 vehicles. Advancements in simulation technology that supported war gaming were not motivated by resource conservation; but rather by the logistics of conducting large-scale exercises which were impractical and sometimes prohibitive.

The simulation technology developed because of this impracticality provided the basis for today's operator and team training devices where energy conservation is a specific objective. At the single and multi-unit tactical training level, use of such systems as the Antisubmarine Warfare tactical trainers, and the Tactical Advanced Combat Direction and Electronic Warfare training complexes leads to significant resource savings when compared with the resources required for the corresponding operational training.

In the introductory remarks to the last year's conference, I reported on the capabilities of training devices in the inventory. The resource savings in men, fuel, weapons, and supply support for equivalent operational training (143,000 weapons; 140,000 flight hours; 140,000 ship hours; and 21,000 submarine hours) is staggering for one year. Comparative ratios for energy conservation range from 10:1 up to 100:1 depending upon the platform type. Associated manpower savings approximate 5:1 for aircraft, 25:1 for submarines, and can exceed 50:1 for surface ships. These factors are compounded

by the multiple support and target platforms participating in the exercises. Resource savings attributable to simulation technology are estimated to preclude billions of dollars of costs annually.

The space and power requirements of trainers have been increasing steadily. For example, the addition of visual and motion systems to basic flight and weapons system trainers within the past few years has influenced this trend. Therefore, the second area where simulation can effect savings in resources is through the optimization of the trainer design itself. Advances in digital technology such as microminiaturization, large scale integration and compact and low-cost mass storage systems have lead to reduced space and power requirements. The computer-generated imagery systems, for example, require much less power and space than a camera model board system given comparable system training performance. The use of commercially developed components and systems with proven performance, maintainability and reliability reduces development risk, time and cost. These practices conserve critical developmental resources such as design engineering and the associated manufacturing and testing activities.

The third area where simulation contributes to the conservation of resources relates to reductions in the staffing levels for training systems. The power of the digital computer coupled with its low cost permits the incorporation of instructional system features previously performed by operators and instructors. The advantages to be accrued from the judicious application of CAI and CMI to major training systems have not been fully exploited. The application of these features is not without agony, however. In order to implement the instruction system through computer software, the courseware must be defined in full detail, at best this is a difficult task.

Another area where simulation technology will lead to reduced staffing requirements is through utilization of voice synthesis technology. Machines that listen and react to trainee orders, or talk to the trainee based on information available in the computer, reduce the requirement for operators. The basic concept has already been validated in the laboratory.

Significant progress has been made in simulation technology since the first conference was held in 1966. The utilization of training devices in the inventory has resulted in substantial savings of resources. The role that simulation will play in the future is probably beyond our capability to comprehend. The goal of this conference then, is to act as a catalyst and substantially enhance the training process and operational readiness while making substantial reduction in the resources required to conduct that training. The papers that will be presented in the next 2-1/2 days report on a broad spectrum of subjects relating to simulation and training.

ABOUT THE AUTHOR

MR. G. VINCENT AMICO has been Director of Engineering at the Naval Training Equipment Center since 1971. He graduated from New York University with a Bachelor of Aeronautical Engineering in 1941. He was awarded a Masters in Business Administration from Hofstra College in 1954 and a Master of Science in Engineering from Florida Technological University in 1973. Mr. Amico worked on the design of naval aircraft as a stress analyst and project stress engineer with the Curtiss-Wright Corporation from 1941 to 1945. He entered the Armed Forces in 1945 and was assigned to the Static Test Unit of the Structures Laboratory at Wright Field as a structure research engineer. Upon leaving the service in 1947, Mr. Amico joined Republic Aviation Corporation with responsibility for preliminary design of missile and advanced aircraft systems. He joined the Center in the fall of 1948 as a project engineer in the Flight Trainers Branch. Since then he has progressed through the engineering organization, holding positions as Head of the VA-VP OFT Branch; Head of the Aviation Trainers Division; Deputy Director and Chief Engineer of the Special Projects Office and Director of the Sea Warfare Trainers Department. During this time, he was responsible for the development and production of a wide variety of training devices in all warfare areas. Mr. Amico is a member of Tau Beta Pi and Alpha Pi Mu Honorary Engineering Fraternities, American Society of Military Engineers, Society for Experimental Stress Analysis, Research Society of America, Sigma Xi, the American Institute for Aeronautics and Astronautics, and the Armed Forces Communications and Electronics Association. He was past Chairman of the New York section of the Institute of Aerospace Science and the Orange Chapter of the Armed Forces Communications and Electronics Association. Mr. Amico holds two patents and has presented a paper to the Institute of Radio Engineers on Synthetic Training for Space Flight. He co-authored a paper on "The Application of System Dynamics Techniques to the Modeling of the Military Training System" for The Seventh Annual Simulation Symposium.

PERFORMANCE EVALUATION: THE KEY TO SYSTEM EFFECTIVENESS*

ROBERT P. FISHBURNE, JR.
Calspan Corporation

Evaluation in a comprehensive ISD-based program must be directed toward both formative and summative measures. To be operationally feasible, these measures must then be integrated into an organized data base. Finally, evaluation must be tailored to the particular course structure and learning strategies inherent in the system under analysis.

Such an evaluation system has been designed for the Navy's E-2 aircrew training program, which is currently under development. Measures of learning acquisition, retention, and transfer have been integrated into a progression of cognitive, practice, and sortie/scenario type lessons. The proposed evaluation system then provides for a sophisticated computer data base, the Versatile Training System with associated analytical programs. Figure 1 presents a model of the information flow within this evaluation system.

Formative Evaluation is the initial development component which consists of Quality Control and Revision input to the Curriculum. Quality Control procedures involve the application of acceptance checklists to storyboard or other preliminary draft instructional materials, while revision is based upon lesson, modular, and course level data from materials tryout.

Summative Evaluation provides Quality Control input to the Curriculum via Revision after the program has been implemented in its entirety. This component of the overall evaluation model serves the functions of both an internal and an external validation of the curriculum as well.

The Versatile Training System[1]. provides the computer data base component of the evaluation model which forms the heart of the system. This data base begins with all Instructional Systems Development (ISD) documentation leading to initial development of the curriculum and is expanded to include updates from system changes and revision from Formative Evaluation and Summative Evaluation. These data sources are processed by the VTS which documents and facilitates curriculum revisions and provides validation reports to training management.

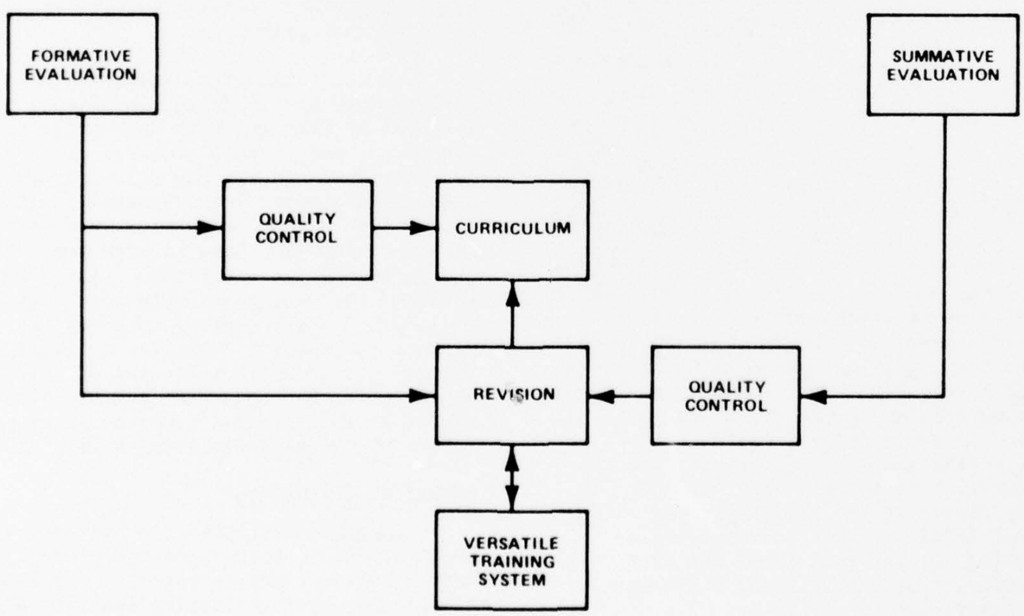

Figure 1. Evaluation Model

*This research was supported under contract N61339-77-C-0003, "E-2 Instructional Systems Development (ISD)," for the Naval Training Equipment Center, Orlando, FL.

The evaluation model presented in Figure 1 is further defined by a performance assessment strategy illustrated in Figure 2. This strategy applies to both formative and summative evaluation, with differences occurring only in data collection techniques and areas of emphasis. Each component of the strategy as it applies to the two forms of evaluation is detailed below.

FORMATIVE EVALUATION

Formative Evaluation is applied to the three-part training strategy involving cognitive, practice, and sortie/scenario lessons in a continuum from learning acquisition to retention and transfer. In consonance with the performance-oriented approach to aircrew training upon which the E-2 ISD program has been based, learning is evaluated (1) in the cognitive setting where the academic prerequisites of a skill are developed, (2) in the practice setting where the actual component skills are developed, (3) in the sortie/scenario setting where skills are integrated and applied, and (4) in the broader setting of course level objectives and criteria. The purpose of the overall Formative Evaluation is therefore a method of collecting and organizing data which contributes to curriculum development at the lesson level, but also at the modular, supramodular, and course level. Thus, no data is viewed only in isolation. Rather, it is available for a systems approach to analysis.

Cognitive Acquisition can be measured by performance on multiple-choice tests given at the completion of a lesson in a carrel or classroom. For empirical validity, a pretest-posttest strategy offers a viable approach to its employment. This assessment at the lesson level, however, can be enhanced through an analysis of both instructional frames (or teaching points) and test items. Data for the analysis of instructional frames in tape-slide sequences are derived from subjects' comments which are solicited after the presentation of each slide and its accompanying narration. Within this strategy, test items related to the frames are also presented on an individual basis. All aspects of the teaching points can thus be evaluated in this manner. Whether a deficiency exists in the narrative, the slide, the compatibility of the narrative-slide combination, or the test item, the data are available for analysis and subsequent input to revision.

Cognitive Retention is another aspect of Formative Evaluation when viewed in its broadest sense. This can be evaluated by repeating the lesson post-test after a two-week delay. While such a strategy goes beyond the typical Materials Tryout scheme, it can be conducted on a small group basis.

Practice Acquisition is the first step in the application of cognitive learning to the performance setting and in development component skills. While Materials Tryout centers upon skills data as measured by simulator performance, the Formative Evaluation must also identify weaknesses in the transfer of the prerequisite cognitive learning. Accordingly, data collection consists of two facets. First, the instructor records time and number of trials to criterion on the practice test. Then, performance deficiencies are further evaluated by instructor ratings of "headwork" vs. psychomotor skills deficiencies and by subjects' comments which are solicited as problems appear within the practice session. If the deficiency is judged to be a psychomotor problem, subsequent revision must address refinements to the practice session. If, on the other hand, the deficiency is judged to be a "headwork" problem, a secondary analysis must center upon defining the problem type as one of Cognitive Acquisition, Cognitive Retention or Cognitive Transfer.

The final component of the Formative Evaluation focuses upon the end-of-course objectives, successful performance on the NATOPS exam and subjective assessments. Such measurement will require the development of questionnaires to be administered to both trainees and instructors.

The above described Formative Evaluation strategy appears to integrate objective measures of learning with subjective assessments in a manner that accounts for both learning types (i.e., Cognitive, Practice, and Sortie/Scenario) and learning sequences (i.e., Acquisition, Retention, and Transfer). The resulting data base is both comprehensive and useful to the curriculum. To be complete, however, the Formative Evaluation must also include a Quality Control component as indicated in Figure 1. Quality Control in the form of a systematic screening of all storyboards prior to production and materials tryout is an essential function to be performed by Media Specialists as well as SMEs.

SUMMATIVE EVALUATION

Summative Evaluation is best viewed as a dual-purpose component of the overall evaluation system. One purpose is to provide training program validation against base-line data from the former training program and the fleet. The second purpose is to provide input to Management Feedback and Quality Control. The former purpose is achieved as the end product of the fully implemented program and requires a comprehensive one-time data collection effort. The latter purpose

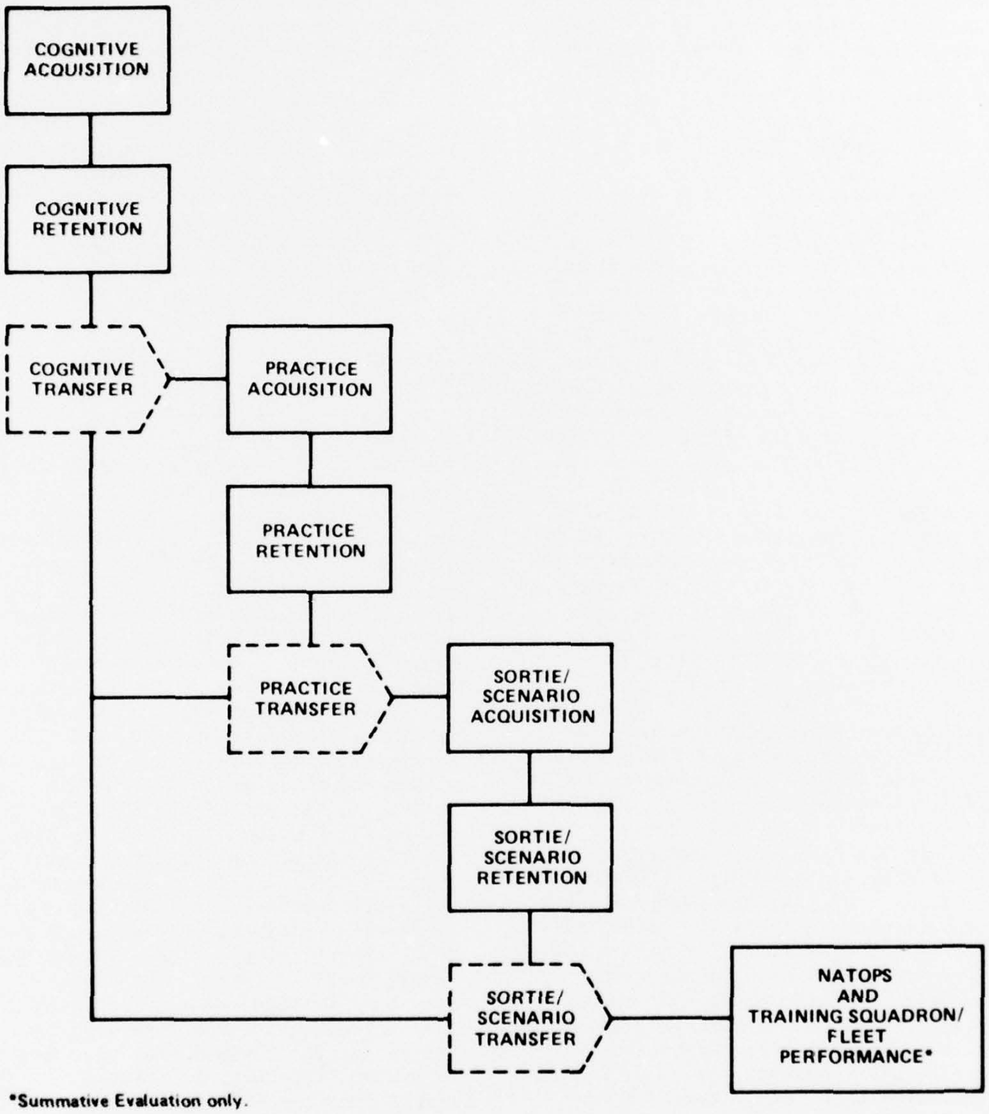

Figure 2. Performance Assessment Strategy: Formative and Summative Evaluation

requires a continuing activity and is one that periodically results in reports to management and revision to the curriculum.

The Summative Evaluation strategy can be compared to the previously presented Formative Evaluation strategy as the basic structure of learning types and learning sequences remains essentially the same. The only difference in evaluation structure lies in the absence of the Retention Component. While this component remains of interest to Summative Evaluation, it is subsumed under the Practice and Sortie/Scenario components where it takes on an adaptive function.

While the structure of the Summative Evaluation strategy closely parallels that of the Formative Evaluation strategy, data collection procedures require more significant changes. Cognitive Acquisition is concerned only with post-test data (except when an advanced student challenges a lesson with a pre-test). Records are therefore compiled on time and number of errors to criterion. Practice Acquisition is concerned with performance tests data (time and number of trials to criterion) as in Formative Evaluation, but subjects' comments are no longer recorded. Cognitive Retention is measured on an adaptive testing basis when an instructor notes an apparent "headwork" deficiency. Scenario Acquisition utilizes the same techniques as Practice Acquisition, except that the adaptive testing strategy shifts from cognitive to practice. The NATOPS exam and Fleet Performance provide the final validation data. That portion of end-of-course data which includes NATOPS scores and questionnaire responses related to graduates of the ISD-based program contributes also to improvement of the course through Revision specifications.

The Summative Evaluation represents a shift not only from small group to large group data collection, but also from materials tryout to student performance. The former emphasis provided by Formative Evaluation contributes to curriculum development (including initial revision), while the latter emphasis contributes to validation, revision, and maintenance. Both Formative and Summative Evaluation are necessary, however, and can be particularly useful when integrated by such a Training Feedback mechanism as the Versatile Training System.

VERSATILE TRAINING SYSTEM

The Versatile Training System has been planned to fulfill the role of an ISD data mechanism in the E-2 training program. A tentative conceptualization has been developed and is presented in Figure 3. To provide a more complete utilization of VTS for training feedback, however, its role has been extended to include Evaluation Data and Revision Data.

ISD inputs into VTS consist of NATOPS, software, hardware, and tactical documentation. These inputs are reflected in a Task Analysis (including a Tactical Task Listing) either initially or through updates generated by system changes. These, in turn, provide input to Behavioral Objectives which are further defined as Training Objectives -- either Cognitive/Enabling or Practice and Sortie/Scenario. Cognitive and Performance Tests then follow from the Training Objectives. Lesson Specifications which provide both Teaching Points and Media Support reflect the culmination of all the above described data bases. The Course Data Base finally reflects the output of development in consonance with the Lesson Specifications. Evaluation Data and Revision Data are two additional sources which operate on the system in the manner indicated in Figure 1.

EVALUATION INSTRUMENT DATA FLOW

Figure 4 presents a conceptualization of the evaluation instrument data flow which corresponds to the system described above. Lessons are developed by Navy Training Squadron personnel based on specifications prescribed by the contractor after a comprehensive analysis. An acceptance Checklist is then applied to the instructional materials to assure adequacy at the storyboard or rough draft level. Materials Tryout follows after production of these materials. This phase of the Formative Evaluation makes use of three instruments in the small-group setting: a Tape-Slide Form, a Classroom Presentation Form, and a Practice & Sortie/Scenario Form. Each is used as appropriate for the type of instruction under evaluation. At the end of the Formative Evaluation period (just prior to actual training program implementation) the Formative Evaluation: Critique is administered in questionnaire form to all participants in the Materials Tryout. Here attitudes, opinions, comments, and recommendations are solicited at the Lesson, Modular and Course level. Finally, the Formative Evaluation data is supplemented with measures of learning effectiveness (learning time and number of errors) derived from the lesson Testing following each unit of instruction. Cognitive Tests, Practice & Sortie/Scenario Tests, and NATOPS Evaluation Worksheets provide this data.

Summative Evaluation begins after the training system has been revised on the basis of Formative Evaluation data, and is concerned with the fully implemented program. As in Formative Evaluation, Testing provides the essential empirical data. Such data is then supplemented with the Summative Evaluation: Critique which is a questionnaire administered to all course graduates and staff personnel and the "administrative Data Sheet" which is the responsibility of the Training Squadron. With the

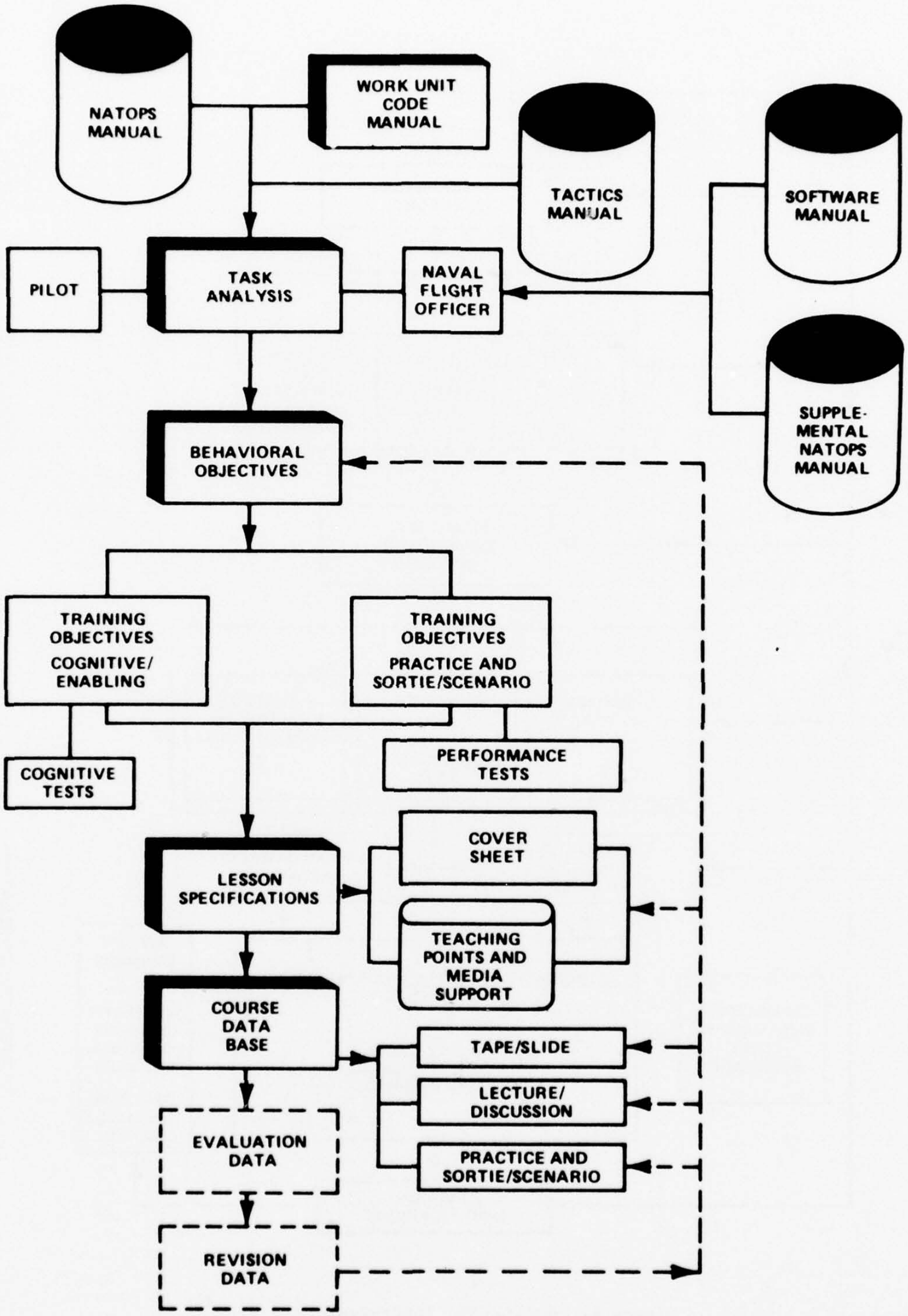

Figure 3. Versatile Training System(VTS)[2].

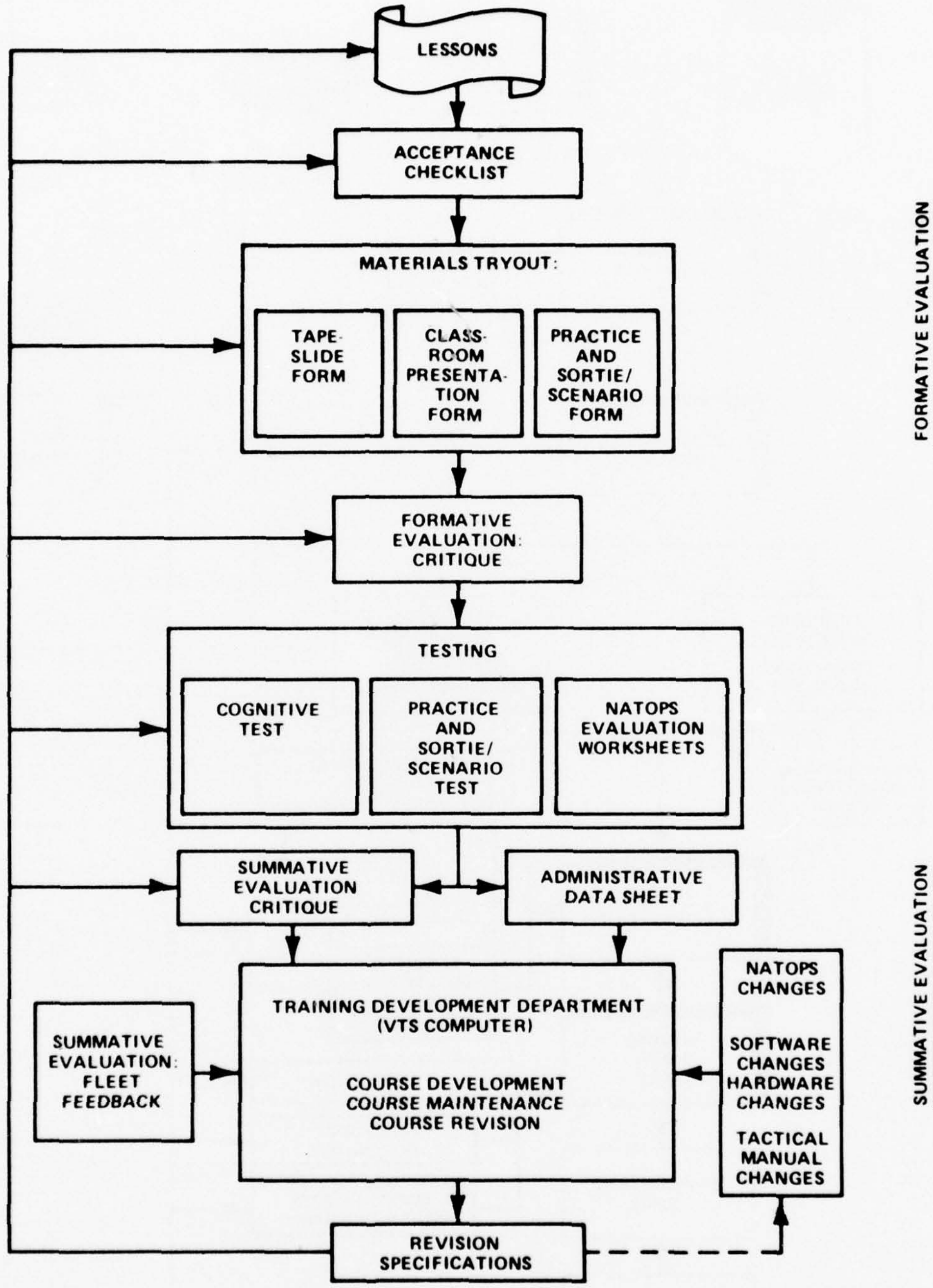

Figure 4. Evaluation Instrument Data Flow[3].

additional input of a questionnaire evaluating fleet performance (the Summative Evaluation: Fleet Feedback Instrument) the Training Squadron processes the Summative Evaluation data and updates the system inputs (NATOPS Changes, Software Changes, Hardware Changes, and Tactical Manual Changes) to produce Revision Specifications. Recommendations are contained therein which may affect the entire training system with the intent of controlling and enhancing its maintenance and efficiency.

FOOTNOTES

1) The Versatile Training System is a development of the Naval Weapons Center, China Lake.

2) Figure 3 was developed by Mr. J. B. Flynn.

3) Figure 4 was developed by Mr. E. R. Pennington.

ABOUT THE AUTHOR

DR. ROBERT P. FISHBURNE, JR. *is a Senior Psychologist with Calspan Corporation's Human Factors Section. He has more than six years experience in military psychology, three of which were spent as a Naval Aerospace Experimental Psychologist. His research interests have ranged from psychmotor performance measurement, to readability, to Instructional Systems Development (ISD). Currently at Calspan, he is principal investigator and field-office director in the development, implementation, evaluation, and revision, of an ISD-based training program for the Navy's E-2 aircrew. He holds an M.A. degree in experimental psychology from Georgia Southern College and an Ed.D. degree in curriculum and instruction (research methodology and statistics) from Memphis State University.*

A PERFORMANCE MEASUREMENT SYSTEM FOR TRAINING SIMULATORS

R. D. GRAVES and C. F. KUPIEC
General Physics Corporation

SUMMARY

Unscheduled power plant outages are very costly and waste energy because that electrical energy must then be transmitted over longer distances from other plants to the locality whose power station is out-of-service. Better trained plant operators as well as better designed plant control and safety systems are germaine in this day and age when our world's emphasis is on conservation of natural resources.

This paper presents a Performance Measurement System that can be utilized for optimizing operator training efforts along with collecting man-machine operational research data on a training simulator. This system was developed for the Electric Power Research Institute (EPRI) and further work on this project is continuing. This paper presents a basic introduction to the system, methodology incorporated in its design, data and results obtained, as well as future plans for the coming three-year term.

I. INTRODUCTION

1.1 Background

Full-scale, real-time simulators have become a key element in the training of nuclear power plant operators. These simulators provide effective operational training without costly plant downtime and they permit training on important abnormal and emergency conditions which cannot be conducted on an operating plant. In addition to their direct training value, these simulators offer a unique opportunity to investigate important aspects of power plant operation. In 1975, the Electric Power Research Institute (EPRI) initiated a program to investigate the use of training simulators for the following purposes:

- To provide an empirical data base for statistical analysis of operator reliability and for allocation of safety and control functions between operators and automated controls.
- To develop a method for evaluation of the effectiveness of control room designs and operating procedures.
- To develop a system for scoring aspects of operator performance to assist in training evaluations and to support operator selection research.

This effort is directed by Dr. Randall W. Pack, Nuclear Engineering and Operations Department, EPRI, and is advised by a Utility Advisory Group (UAG) composed of representatives of utility companies owning or having on order a nuclear power plant simulator. Project participants include individuals and organizations with expertise in nuclear power plant operations and training, simulator design and construction, mathematical modeling of human operator performance, human factors engineering, and selection testing.

In the first phase of this program, EPRI contracted with The Singer Company, Simulation Products Division, to study the feasibility of a standardized performance measurement system using simulation techniques. Singer concluded that such a program is feasible and recommended that one or more prototype performance measurement systems be developed and implemented on selected current generation nuclear power plant simulators.

Subsequent to the Singer study, the Tennessee Valley Authority (TVA) expressed interest in participating in operator performance measurement research using the power plant simulators being constructed at the TVA Power Production Training Center at the Sequoyah Nuclear Power Plant site near Daisy, Tennessee. This Training Center, equipped with simulators for the Sequoyah PWR Nuclear Power Plant, the Browns Ferry BWR Nuclear Power Plant and the Cumberland fossil fueled plant, will provide all the facilities needed for a comprehensive program applying simulation techniques to the study of plant operations.

Having concluded that development of a performance measurement system is feasible and having identified simulator facilities that could be used for this purpose, EPRI initiated a one year project to develop a prototype Performance Measurement System for Training Simulators. Work was started on 1 May 1976 and the initial series of four exercises was pilot implemented on the Browns Ferry Simulator at the TVA Power Production Training Center during the week of 21 March 1977.

The one year feasibility demonstration project demonstrated that the Performance Measurement System has excellent potential for supporting research in the following areas:

- Training techniques and methodology
- Human factors aspects of control room design
- Personnel selection
- Operator reliability analysis

1.2 Applications of the System

The techniques for developing a Performance Measurement System described in this paper can be adapted to any current plant simulator. Data collection, performance evaluation, and research programs can be prepared in the fashion for any application - be it aircraft, chemical plant, or military trainer.

Simulator Performance Measurement Systems appear to be potentially very useful to the Navy training community. In the area of training evaluation, they offer the potential for quantitative, standardized evaluation of a ship or aircraft ASW team, a flight crew, or an air defense team. Not only could the operational readiness of the team be measured against a known standard, but the effectiveness of the training could be assessed by comparison of pre- and post-training evaluations. The use of an impartial instrument such as the simulator computer to assist with performance evaluations can also provide more consistent and useful measures of performance than those generated by human evaluators alone, especially in an environment where instructor turnover is relatively rapid.

For the Navy, tactical development requires data on man-machine performance, in the same manner that such data is needed for research in the EPRI Performance Measurement System. With a high fidelity simulation, the effectiveness of new tactics and hardware can be evaluated in the semi-controlled environment of the training simulator. Operator performance and hardware deficiencies can be identified precisely, and appropriate action initiated to correct these problems. In an era of funding restraints, the use of training simulators to develop such operational data appears to be much more cost-effective than the use of numerous large-scale fleet exercises. Additionally, data collected in real-time on the trainers is subject to far fewer perturbations than data collected at sea. Obviously use of sophisticated simulators will not eliminate the need for training exercises at sea, but a proper mix of simulator and at-sea exercises could result in improved tactical development data, gathered in a more cost-effective manner.

1.3 Project Status

The following summarizes the progress made on this project between January 1, 1977 and May 1, 1977.

- The prototype Performance Measurement System was successfully pilot implemented at the Browns Ferry BWR Simulator. Four test exercises were run several times during the pilot implementation week. These test exercises were: Reactor Criticality, Plant Startup, SCRAM from High Power, and Main Steam Isolation Valve (MSIV) Closure.

- This paper contains the data and analysis for three of these exercises, namely: Reactor Criticality, Plant Startup, and SCRAM from High Power. These three exercises were carefully reviewed by General Physics and several computer program updates were made for each. It is believed that these three exercises are presently complete. The evaluation computer program for the MSIV exercise is currently nearing completion at the time of this writing.

- Human factors specialists from Lockheed Missiles and Space (LMSC) observed the man-machine interfaces associated with the exercises as they were being run on the Browns Ferry BWR Training Simulator. They also interviewed each of the participants following the exercises. The report of their findings is published in a report entitled "Pilot Study Performance Measurement System for Training Simulators," EPRI Project RP 769-1, 21-25 March 1977, by J. L. Seminara and S. K. Eckert, April, 1977.[1]

- Dr. Richard S. Barrett, Director of the Applied Psychology Division of

[1]These reports are included in a General Physics Report entitled "Electric Power Research Institute Project RP 769-1, Performance Measurement System for Training Simulators, Third Progress Report, GP-R-321, May 27, 1977, by C. F. Kupiec and R. D. Graves.

the Stevens Institute of Technology, observed the pilot implementation of this prototype system. He has prepared suggestions with regard to research in operator selection and presented them in a report entitled "Report of Observations Made on March 21 and 22 at the TVA Simulator."[1]

- Dr. Thomas D. Sheridan of MIT, a member of this project team, observed the pilot implementation exercises and has made suggestions regarding future evaluation exercises. He suggests that Casualty Identification and Control Drills (CICD's), of short time duration, be incorporated for some future exercises. Exercises of this sort would be a potential source of much operational research data because each CICD could be performed many times by many operators. He has also suggested drills of longer time duration to provide data relevant to the ANSI-N660[2] decision concerning the reliability of operator diagnosis and response as a function of time. Dr. Sheridan has prepared preliminary ideas for utilization of these exercises for future research.

- The computer data presented is also compared with the subjective instructor's evaluation for each of the test exercises. The instructor data proved invaluable in verification of the validity of the test exercises.

- The use of exercise videotaping was incorporated during the test exercises. This was a valuable review tool for the evaluator and operator both.

Refer to Figure 1.

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[1]These reports are included in a General Physics Report entitled "Electric Power Research Institute Project RP 769-1, Performance Measurement System for Training Simulators,"Third Progress Report, GP-R-321, May 27, 1977, by C. F. Kupiec and R. D. Graves.

[2]ANSI Standard N-660 "Criteria for Safety Related Operator Actions." The purpose of this proposed standard is to provide criteria to decide whether initiation or adjustment of a safety system provided to mitigate the consequences of a design basis event may be accomplished by a human operator or must be augmented by an automatic protection system.

1.4 Project Organization

In organizing this project, EPRI assembled a well-balanced team with expertise in several different fields to ensure that the prototype performance measurement system would, to the maximum extent practicable, achieve the program goals. The project organization, illustrated in Figure 2, includes expertise in nuclear power plant operations and training, simulator design and construction, mathematical modeling of human operator performance, human factors engineering, and selection testing.

Additionally, and of paramount importance to this development effort, the project is reviewed by a Utility Advisory Group (UAG) composed of representatives from utility companies which own or have on order a nuclear power plant training simulator. By having first-hand input from the UAG, other project participants can help to assure that the project is conducted in a manner useful in the utility companies.

The Utility Advisory Group is currently comprised of representatives from the following utility companies:

- Carolina Power and Light Company
- Consolidated Edison Company of New York
- Duke Power Company
- Pennsylvania Power and Light Company
- Tennessee Valley Authority
- Virginia Electric and Power Company
- Washington Public Power Supply System
- Arizona Public Service Company

Additionally, representatives of the ANS-50 committee who are currently developing ANSI Standard N-660, Criteria for Safety Related Operator Actions, have recently begun formal interaction with the project team. Empirical data generated from simulator exercises can be of great value to this committee, and their participation is intended to assist the project in developing and providing this data in the appropriate form.

II. COMPUTER EVALUATION PROGRAM METHODOLOGY, PROGRAM WRITING AND DEBUGGING

2.1 Methodology

The programming goals of the current EPRI project were set forth as follows:

- The construction of a real-time simulation module to collect and permanently store on magnetic tape the entire contents of the simulator I/O buffer at a rate

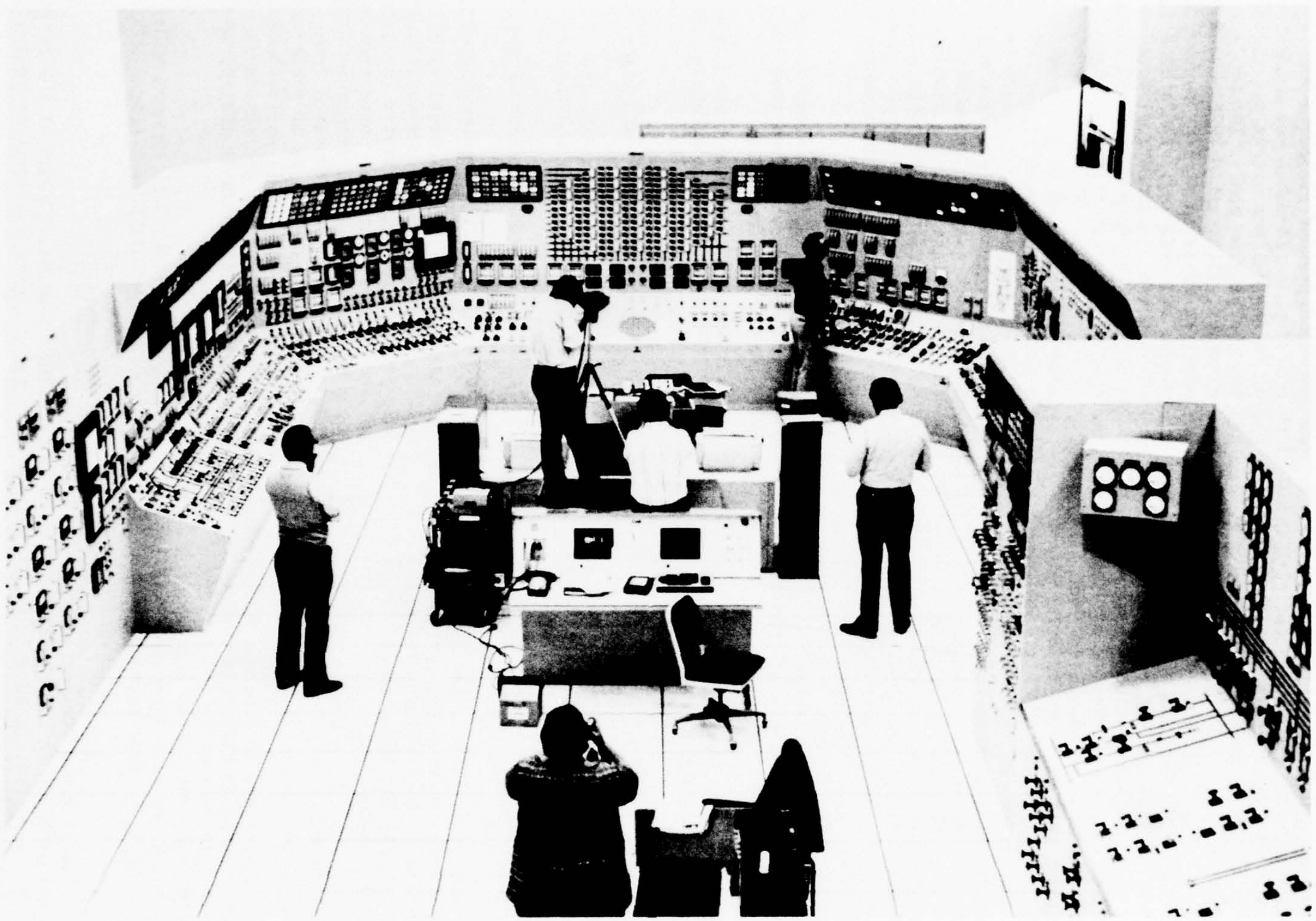

Figure 1. Brown's Ferry BWR Simulator Control Room at the TVA Power Production Training Center during the implementation of the Prototype Performance Measurement System.

INDIVIDUAL/ORGANIZATION	PROJECT INVOLVEMENT
Dr. Randall W. Pack • Nuclear Engineering and Operations Department, EPRI	• EPRI Project Manager
Utility Advisory Group (UAG) • Representatives from utility companies which own or have on order nuclear power plant simulators	• Advise the project to ensure that the system is implemented in a manner that is most beneficial to utility companies
General Physics Corporation • A leader in providing training services to the nuclear industry	• Responsible for EPRI implementation of the system
The Singer Company, Simulator Products Division • A leader in the design and production of simulators for the military and for industry	• Provide expertise on simulator hardware and software
Dr. Thomas B. Sheridan • Professor of Mechanical Engineering, Massachusetts Institute of Technology and Head of the Man-Machine Systems Laboratory at MIT. • Has conducted extensive research on mathematical models of human operator performance.	• Advise the project to ensure that it is used effectively to support the development of operator models and the conduct of operator reliability research
Lockheed Missiles and Space Company • Has extensive experience in human factors engineering for the aerospace industry. • Has completed a study of human factors engineering aspects of nuclear power control room design.	• Advise the project to ensure that it is used effectively in support of research directed at improved control room design.
Dr. R. S. Barrett • Professor, Stevens Institute of Technology • Has developed and critiqued Selection Programs for numerous industrial clients, including utility companies.	• Advise the project to ensure that it is used effectively in support of personnel selection research

Figure 2. Project Organization, Performance Measurement System for Training Simulators

sufficiently rapid to accurately determine the state of the particular piece of datum being sampled.

- The construction of a set of computer algorithms to evaluate training exercises using as a data base the data collected and stored on magnetic tape via the real-time data collection program.

In these data collection programs, a complete set of boolean and analog data is collected, which at a given instant of time represents the state of the several thousand switches, lights, meters, recorders, etc., present in the plant control room. The reason for collecting all of these data is that certain data will be utilized in research programs to identify man-machine operational characteristics while other data will be used in evaluating the operator's performance for the given exercise.

The principal function for maintaining a record of all data is to enable the research analyst to go back and evaluate other parameters at a later time if deemed necessary.

The research effort currently under way incorporates reviewing an operator's performance in detail so as to better define the man-machine operational strengths, as well as weaknesses. In this way, a better understanding of operator reliability can be obtained as well as the pin-pointing of plant control shortcomings. This type of data would be beneficial for control room design as well as identifying incorrect operational techniques.

2.2 Program Writing and Debugging

There are five basic steps in the construction of any computer program:

- Construct Algorithm
- Generate Computer Code
- Determine Input Data
- Determine Output Data
- Debug Exercises

The first step, "Construct Algorithm," is simply the construction of the logical rules by which one evaluates whatever one wishes to evaluate and is independent of any particular computer language. This is the most crucial step in the construction of an evaluation program and it is necessary that it be done in conjunction with a knowledgeable reactor operator instructor, preferably the person who drafted the exercise. Close cooperation between programmer and instructor on this step will result in a good evaluation program in a minimum amount of time.

The second step, "Generate Computer Code," is a FORTRAN realization of the evaluation algorithm. In other words, the algorithm is cast in a language the computer understands. The evaluation exercises written for this project were written in Extended FORTRAN IV except for certain data transforming subroutines which had to be written in Assembly Language. The structure of the code for the four programmed exercises is not identical in that to some extent programming these exercises was a learning process for the programmer. In the programming of future exercises, it is suggested that a technique called "structured programming" be adhered to as closely as possible. In this technique, the code is generated from top to bottom in such a manner that each block of code has only one entry point, one exit point and no unconditional branches. This means that each block of code is independent instead of interdependent as is the case in most computer programs and can be debugged easily.

In the third step, "Determine Input Data," is lumped together a number of substeps: (1) the simulator instructor and the programmer must decide together what data is required to evaluate each step of the exercise. This data could be a switch position, a lamp output, a rod position, a meter indication, or a combination of one or more of the above. After these determinations have been made, the programmer must consult with the simulator manufacturer to determine where in the I/O buffers this data resides and in what form. For example, a certain piece digital datum needed may be bit 13 of the 631 word of the I/O. After the locations and forms of the data are obtained from the simulator manufacturer, the programmer must determine how to translate this data into a FORTRAN representation. A number of standard FORTRAN callable assembly language subroutines have been written to accomplish this. For example, the standard subroutine TEST BITS will process any number of bits of an I/O word and return to the FORTRAN program the boolean representation of those bits.

The fourth step, "Determine Output Data," is really only a programming step in the sense that the program must produce a printout of error messages and scores. The form of the programs used to produce the printouts is now standard. However, in spite of this, a large amount of time and programming effort is expended in producing the printouts. This is because a given exercise can have a large number N of possible errors associated with it. A

printout requires 6N FORTRAN error statements. Currently we are devising a method for the follow-on project which will use N free form error messages as input data to a standard print subroutine. The standard print subroutine would utilize the alphanumeric string manipulation capabilities of FORTRAN via the encode/decode subroutines. The use of this method will greatly reduce the time and effort currently spent on this step of the programming.

The last step, "Debug Exercise," is another one which requires close cooperation between the programmer and simulator instructor. First, the input data to this evaluation program should be printed out and closely inspected to ensure that the I/O locations were correct and that the data subroutines are interpreting the data correctly. Next, the evaluation program should be run using data from exercises which are expected to be error free and exercises which contain known errors. The printouts from these exercises should then be carefully scrutinized by both simulator instructor and programmer and any discrepancies noted. The errors which are found are usually simple and easy to correct. However, in exercises which contain complex process control blocks, nonprogramming errors can occur which indicate the process is being misevaluated. Major revision of the code may then be necessary. It is for this reason that the use of structured programming techniques is recommended. If the program is structured, the offending block of code will be logically independent of other program blocks and can be easily reprogrammed.

III. PILOT IMPLEMENTATION DATA AND RESULTS

3.1 Schedule

Pilot Implementation of the Performance Evaluation System was performed during the week of March 21, 1977. It took place at the Browns Ferry simulator at the TVA Power Production Training Center. This consisted of conducting each of the four pilot exercises utilizing TVA operators, a training coordinator from Washington Public Power Supply System and members of the General Physics training organization. The four exercises utilized in this pilot implementation were:

- Criticality (Individual Exercise)
- SCRAM (Individual Exercise)
- Startup (Group Exercise)
- Main Steam Isolation Valve Closure (Group Exercise)

1. Reactor Criticality (Individual Exercise

SCENARIO

The reactor is shutdown by approximately $-1\%\Delta k/k$. Seven control rods must be sequentially withdrawn to achieve criticality. During this time, the reactor operator must follow correct control manipulations to enable the reactor to achieve criticality. The exercise is terminated when the reactor vessel water temperature is increased by approximately $10^{\circ}F$.

2. *Reactor Scram From Power Operation* (Individual Exercise)

SCENARIO

The plant is operating at $\approx 50\%$ power. After several minutes of steady state operation, the generator trips due to a single phase fault between the generator and the generator breaker in the switchyard. The operator must respond to this trip and the resultant reactor scram without help from additional operators. The plant will not be restarted. The exercise is terminated upon being ready to restart or commence cooldown.

3. Plant Startup (Group Exercise)

SCENARIO

Reactor is critical at 10% power with approximately 3 Bypass Valves open. Reactor water level is in manual control with the "A" Reactor Feed Pump in service. The main turbine has been on the turning gear for two hours in preparation for startup following turbine maintenance.

Startup and synchronize the Unit in accordance with correct procedures. Use the simulator telephone to request the performance of evolutions required outside the control room. The reactor operator is responsible for the operation of the reactor including water level and reactor auxiliaries. The Turbine operator is responsible for all evolutions. Record the events in the Daily Journal.

4. Main Steam Isolation Valve Closure (Group Exercise)

SCENARIO

The plant is operating at full power. After several minutes of operation, the generator trips due to

a single phase fault between the generator and the generator breaker in the switchyard. The crew (2 operators) must respond to this trip and the resultant reactor scram and *Main Steam Isolation*. The objective is to verify the safe shutdown of the reactor and turbine and to stabilize control of the reactor pressure and water level. The plant will be cooled down in the isolated condition. The exercise is terminated when cooldown has been established.

3.2 Scope

The principal purpose of this Pilot Implementation was to demonstrate the feasibility of the Performance Evaluation System. It was also utilized to obtain further information on the potential uses of the system for training and research. In addition, valuable data was also obtained to improve each of the four exercises.

This week of simulator exercises was successfully completed at the Browns Ferry simulator. All of the scheduled exercises were completed and the following was accomplished with each exercise:

1. As each exercise was conducted, operational data was collected on magnetic tape. These magnetic tapes were subsequently utilized as data input into the computer program utilized to evaluate the reactor operator performance.

2. During each simulator exercise, one or more experienced evaluators observed the operation and completed an evaluator checklist as the exercise was conducted. It was intended that these subjective evaluations provide a preliminary assessment of how the system performance data correlates with the observations of these experienced observers.

   The subjective instructor evaluations will be used as a rough comparison against the computer results. The details of the computer printout is the subject matter of section 3.3.

3. Each exercise was videotaped, which proved to be most beneficial during the post-exercise interviews and evaluation of each operator's performance on the simulator.

4. A post-exercise operator interview was conducted by the human factors, selection testing, and modeling consultants. The purpose of this interview was to get data on the operator's opinions of these exercises along with his judgement *of the relative difficulty of the* tasks required for performance.

The section which follows includes the details of the computer printout employed in the reactor operator performance evaluation.

3.3 Computer Printout for the Pilot Implementation Exercises

For the purpose of illustration, the complete computer printout facsimile from the first computer graded exercise carried out at the Browns Ferry simulator is presented in this section in Figures 3(a)(b)

A performance summary for each of the pilot implementation runs carried out during this program is presented in section 3.4 along with the instructor evaluation summary for each exercise.

At this time, however, let's consider the information tabulated in Figures 3 (a)(b) Note that the information presented therein is done so in several different ways. This is done so as to enable the instructor to evaluate the student's performance quickly and easily. The following data tabulations are compiled in each computer printout.

1. Event/Error Chronology

   The chronological tabulation of key events along with the errors incurred is tabulated first. Each error is identified according to its type (namely, A, B, C or D). A listing of this type enables the instructor to obtain a broad overview of the student operator's performance in the exercise. Figure 4 includes the compilation of the classification of errors considered in these exercises.

2. Performance Summary

   This portion of the computer printout tabulates the total number of errors incurred along with the maximum possible score and actual score achieved for the exercise. For example, in Figures 3(a)(b) computer printout for the criticality exercise, the operator was responsible for one C-Type error and several D-Type errors in the neutron monitoring portion of his total exercise. The performance summary portion of the computer printout tabulates the criticality

EVENT/ERROR CHRONOLOGY
INDIVIDUAL EXERCISE/REACTOR CRITICALITY
BROWNS FERRY SIMULATOR

Date: 3/21/77
Run I1-1

TIME HR:MIN:SEC	EVENT OR ERROR	TYPE
00:00:00	Start the Exercise	
00:02:41	Operator Commences Rod Withdrawal	
00:07:28	* Failed to Conduct Rod Overtravel Test	B
00:09:44	* Failed to Conduct Rod Overtravel Test	B
00:18:11	* Failed to Conduct Rod Overtravel Test	B
00:24:29	Reactor Critical	
00:28:42	* Failed to Maintain IRM Greater than 15%	D
00:29:11	* Withdraw SRM Detectors Prior to IRM Band 3	C
00:29:18	* Failed to Shift SRM Recorders to Slow	D
00:29:18	* Failed to Maintain IRM Less than 85%	D
00:29:27	* Failed to Maintain IRM Less than 85%	D
00:44:29	Reactor Adding Heat	
01:01:43	* Calculated Heat-up Rate Incorrectly	D
01:01:43	End of Exercise	

PERFORMANCE SUMMARY
INDIVIDUAL EXERCISE/REACTOR CRITICALITY

TASK	TOTAL NUMBER ERRORS OF EACH CLASS A	B	C	D	POSSIBLE SCORE	SCORE	%
I. System Operation							
1. Neutron Monitoring	0	0	1	4	35	27	77.1
2. CRD (Control Rod Drives)	0	3	0	0	28	13	46.4
3. RPS (Reactor Protection)	0	0	0	0	3	3	100.0
II. Process Control							
1. RCS Temperature Control	0	0	0	0	26	26	100.0
2. Reactivity/Power Control	0	0	0	0	18	18	100.0
3. RX Water Level Control	0	0	0	0	15	15	100.0
III. Administrative	0	0	0	1	10	7	70.0

TIME FACTORS	MEAN (MINUTES)	THIS EXERCISE (MINUTES)
1. Start to Achieve Criticality	0	24
2. Criticality to Point of Adding Heat	0	20
3. Total Exercise	0	61

Figure 3 (a). Computer Printout for Criticality Exercise Showing Event/Error Chronology, Performance Summary and Time Factors

ERROR SUMMARY
INDIVIDUAL EXERCISE/REACTOR CRITICALITY

I. SYSTEM OPERATION

1. Neutron Monitoring:

TIME HR:MIN:SEC	ERROR	TYPE
00:28:42	* Failed to Maintain IRM Greater than 15%	D
00:29:11	* Withdrew SRM Detectors Prior to IRM Range 3	C
00:29:18	* Failed to Shift SRM Recorders to Slow	D
00:29:18	* Failed to Maintain IRM Less than 85%	D
00:29:27	* Failed to Maintain IRM Less than 85%	D

2. CRD:

TIME HR:MIN:SEC	ERROR	TYPE
00:07:28	* Failed to Conduct Rod Overtravel Test	B
00:09:44	* Failed to Conduct Rod Overtravel Test	B
00:18:11	* Failed to Conduct Rod Overtravel Test	B

3. RPS:

TIME HR:MIN:SEC	ERROR	TYPE

No Errors in This Task

II. PROCESS CONTROL

1. RCS Temperature Control:

TIME HR:MIN:SEC	ERROR	TYPE

No Errors in This Task

2. Reactivity/Power Control:

TIME HR:MIN:SEC	ERROR	TYPE

No Errors in This Task

3. RV Water Level Control:

TIME HR:MIN:SEC	ERROR	TYPE

No Errors in This Task

III. ADMINISTRATIVE

TIME HR:MIN:SEC	ERROR	TYPE
01:01:43	* Calculated Heat-up Rate Incorrectly	D

Figure 3 (b). Computer Printout for Criticality Exercise
Showing Error Summary

CATEGORY	CLASSIFICATION OF ERROR
A.	Error which would have very serious consequences with regard to reactor safety and operation. Criteria: (1) Operation that results in violation of a Technical Specification safety limit. (2) Operation that results in an unscheduled release of radioactive materials to the environs. (3) Operation that results in equipment damage rendering the plant unavailable.
B	Error which may have, or may lead to, serious consequences with regard to reactor safety and operation or may substantially reduce safety margins. Criteria: (1) Operation that invalidates any assumption in the Safety Analysis. (2) Operation that results in the violation of a Technical Specification Limiting Condition for Operation. (3) Operation that, if uncorrected, could result in a violation of a Technical Specification Safety Limit. (4) Operation that, if uncorrected, could result in equipment damage rendering the plant unavailable.
C	Error which interrupts or causes degraded plant operation but does not affect or threaten reactor safety. Criteria: (1) Operation that results in the initiation of an Abnormal Operational Transient. (2) Operation that violates an approved station procedure. (3) Operation that results in the activation of an automatic protective system.
D	Errors which, unto themselves, do not degrade plant operations directly but which are indicative of faulty judgement or lack of attention to detail and, if uncorrected, may cause or become an error of another category. Criteria: (1) Operation that, if uncorrected, could result in actuation of an automatic protective system. (2) Operation that, if uncorrected, could result in the violation of a Technical Specification Limiting Condition of Operation. (3) Operation inconsistent with accepted "good operating practices." (4) Operation outside of boundaries of "normal operation." (5) Operation that violates an approved station procedure.

Figure 4. Classification of Errors

exercise tasks according to three major categories. These are:

I. System Operation
II. Process Control
III. Administrative

This is quite useful in that it allows the instructor/evaluator to tell at a glance which major areas that the operator-in-training may have had exhibited difficulty.

3. Time Factors

A separate tabulation of the important operational times is tabulated chronologically to identify how long it took the operator to accomplish the assigned task.

4. Error Summary

A complete error summary identified according to assigned task as well as type of error is also tabulated at the end of the computer printout. It is felt that the printout in this manner enables the instructor to review the student's performance in a clear, well-organized manner.

3.4 Pilot Implementation Exercise Data

There were 20 runs carried out to test the feasibility of the performance measurement system for training simulators. These runs included the four exercises discussed in section 3.1.

As was shown in section 3.3, the computer printout data outlines the reactor operator's performance in several different ways.

At this time, let us consider the overall data as compiled during these pilot implementation runs which is currently complete. This data is compiled in a tabular form which compares the objective computer grade with the subjective evaluator's grade for the test exercises. The following figures identify the comparison in performance grading between the two techniques:

- Figure 5, Grading Comparison for the Criticality Exercises
- Figure 6, Grading Comparison for the SCRAM Exercises
- Figure 7, Grading Comparison for the Startup Exercises

A brief perusal of these data discloses that the computer data correlates reasonably well with the subjective evaluations made by the instructor for that particular exercise. However, there are several exceptions to this close correlation in which the instructor evaluation and the computer evaluation are separated by more than several percent.

Although it was not the original intention of this report to evaluate these differences between the two sets of grades, it is believed that in actual practice such differences could arise and would necessarily have to be examined.

Section 3.5 which follows will consider the results of this data evaluation and examine the strengths and possible shortcomings of the computer evaluation technique.

3.5 Pilot Implementation Exercise - Results and Analysis

1. Analysis of the Criticality Exercises

From the computer printout of the performance summary as compared to the instructor evaluation as shown in Figure 5, the major areas of grading differences were in Neutron Monitoring, Control Rod Drive, and Administrative sections.

After a discussion with the instructor/evaluator concerning this exercise the following facts became apparent:

a. With regard to the neutron monitoring system, it was difficult for the instructor to continually determine if all of the IRM detectors were properly on scale.

b. In regards to shifting the SRM recorders to slow speed prior to detector retraction, it was felt by the operator that this task was likely to be forgotten because of other tasks which were more pressing.

c. With regard to the control rod drive section, the computer evaluation program only considered one method of determining if the rod had been properly overtravel tested. In reality however, there is more than one way to validly overtravel test the rod. The computer program is being updated to reflect the ways the rod can be overtravel tested.

EXERCISE NUMBER	(1) 3/21/77 #1		(2) 3/21/77 #2		(3) 3/22/77 #1		(4) 3/23/77 #1		(5) 3/23/77 #2	
COMPUTER / SUBJECTIVE GRADE / EVAL. GRADE	Comp.	Subj. Eval.	Comp.	Subj. Eval.	Comp.	Subj. Eval.	Comp.	Subj. Eval.	Comp.	Subj. Eval.
I. SYSTEM OPERATION										
1. CRD	46.4	60	46.4	100	46.4	100	100	100	100	90
2. NMS	77.1	80	97.1	100	100	100	74.3	100	100	90
3. RPS	100	100	100	100	100	100	100	100	100	100
SUBTOTAL	65.2	72.4	75.8	100	77.2	100	86.4	100	100	90.5
II. PROCESS CONTROL										
1. Reactivity/Pwr. Control	100	90	100	100	100	100	88.9	100	100	80
2. Vessel Level Control	100	100	100	100	93.3	90	100	100	100	100
3. RCS Temp. Cont.	100	100	100	100	100	100	100	100	100	100
SUBTOTAL	100	97	100	100	98.3	100	96.6	100	100	90.5
III. ADMINISTRATIVE	70	90	70	100	100	90	70	100	70	90
SUBTOTAL	70	90	70	100	100	90	70	100	70	90
TOTAL	80.7	84.4	85.9	100	88.1	98.1	89.6	100	97.8	91.9

Figure 5. Reactor Criticality Exercise

EXERCISE NUMBER	(1) 3/21/77 #1		(2) 3/21/77 #2		(3) 3/22/77 #1		(4) 3/23/77 #1		(5) 3/24/77 #1	
COMPUTER / SUBJECTIVE GRADE / EVAL. GRADE	Comp.	Subj. Eval.	Comp.	Subj. Eval.	Comp.	Subj. Eval.	Comp.	Subj. Eval.	Comp.	Subj. Eval.
I. SYSTEM OPERATION										
1. Main Turbine	51.9	50	74.1	80	100	100	100	80	77.8	90
2. Feedwater System	52.2	50	52.2	90	87	100	87	70	52.2	100
3. Reactor Protect.	100	80	100	100	100	100	100	100	100	100
4. Nuc. Instrum.	66.7	60	66.7	90	100	100	33.3	100	100	80
5. Gen,/Electrical	57.1	90	57.1	100	57.1	100	57.1	60	57.1	100
6. RWCU	100	30	100	70	100	100	100	70	100	90
7. Recirc. System	12.5	70	12.5	90	12.5	100	12.5	100	12.5	90
SUBTOTAL	65.1	60.7	70.8	89.1	87.7	100	82.1	78.6	74.5	93.1
II. PROCESS CONTROL										
1. RV Press. Cont.	100	90	100	100	100	100	100	100	100	100
2. RV Wtr. Lev. Cont.	100	60	100	90	100	100	100	90	100	100
3. Reactivity/Power Control	100	100	50	100	100	100	100	100	100	100
SUBTOTAL	100	78.5	92.9	95.7	100	100	100	95.7	100	100
III. ADMINISTRATIVE	0	0	100	90	100	100	100	100	100	100
SUBTOTAL	0	0	100	90	100	100	100	100	100	100
TOTAL	70.8	62.8	75.9	90.3	90.5	100	86.1	82.2	80.3	94.5

Figure 6. SCRAM Exercise

EXERCISE NUMBER	(1) 3/22/77 #1		(2) 3/24/77 #1	
COMPUTER / SUBJECTIVE GRADE / EVAL. GRADE	Comp.	Subj. Eval.	Comp.	Subj. Eval.
I. SYSTEM OPERATIONS				
1. Main Turbine	74.2	90	79.7	100
2. Main Generator	87.2	100	30.8	80
3. Auxiliary Electrical	47.6	90	47.6	100
4. Control Rod Drive	100	100	100	100
5. Reactor Level Control	100	100	100	90
SUBTOTAL	76.8	93.5	66.7	94.8
II. PROCESS CONTROL				
1. Turbine Control	63.6	100	63.6	100
2. Reactivity/Power Control	96.8	100	67.7	100
3. Vessel Level Control	87.0	100	87.0	90
4. Generator Control	27.3	100	27.3	90
SUBTOTAL	69.5	100	62.6	96.6
III. COORDINATION OF OPERATIONS	50	100	100	100
SUBTOTAL	50	100	100	100
IV. ADMINISTRATIVE	100	100	100	100
SUBTOTAL	100	100	100	100
TOTAL	71.5	96.7	68.4	96.6

Figure 7. Startup Exercise

d. In regards to the administrative task of calculating the heatup rate correctly, there were also some grading differences. The computer calculated the average heatup rate over the exercise duration. Some of the operators however, calculated the instantaneous heatup rate at the exercise termination.

2. Analysis of SCRAM Exercises

From the computer printout of the performance summary as compared to the instructor evaluation, as shown in Figure 6, the major areas of grading differences were in Nuclear Instrumentation, Generator/Electrical, Reactor Water Cleanup (RWCU), and Recirculation System.

Following a detailed discussion with the instructor performing the operator evaluations, the following facts were apparent:

a. Some of these SCRAM exercises were terminated early by the instructor simply because the operator had the plant conditions well under control and was obviously handling this situation correctly. The Performance Evaluation System, however, required that the exercise be entirely complete for it to be properly evaluated.

b. What seemed to be a technical difficulty with the simulator may also have been the cause for nuclear instrumentation grading differences. It was noticed during operations that some nuclear instrumentation indications were not functioning normally.

c. Incomplete familiarity with all of the items to be evaluated under each section of the evaluation form also gave rise to further grading discrepancies in the areas of the Generator/Electrical, RWCU, and Recirculation System sections of this SCRAM exercise.

3. Analysis of the Startup Exercises

Technical difficulties with the data tapes of two of the four startup exercises caused them to be incomplete. Hence, only two startup exercises were considered as having valid results. In these two exercises, the same variations between the computer results and the evaluator results as shown in

Figure 7 occurred in the Main Turbine, Main Generator, Auxiliary Electrical, Turbine Control, Reactivity Power Control, and General Control sections.

The startup exercise is a difficult exercise, not only for the operator in training to perform, but also for the instructor to properly evaluate. The difficulty of this particular exercise is perhaps best described by the operators who actually participated in this program.

Four test subjects evaluated the Plant Startup operational sequences for error potential. The Plant Startup exercise tasks which were perceived as being most error-prone are as follows:

a. Checks Units Auxiliary Transformer voltage prior to 4 KV transfer.
b. Maintains transfer voltmeter balanced during turbine loading.
c. Selects and withdraws correct control rods.
d. Maintains reactor vessel level between 28 and 38 inches.
e. Correctly determines the first stage bowl temperature.
f. Verifies that chest warming is off.
g. Verifies lift pump on until > 990 RPM.

3.6 Concluding Remarks

1. Improvement of the Instructor's Capability

The fact that the computer evalation is so complete and exacting, it not only evaluates the operator in training, but it also tends to measure the performance of the instructor's evaluation as well.

It is difficult, if not impossible, for the evaluator to monitor all of the parameters which the computer can do easily, however, with a little practice employing the use of the computer printout results, the instructor will tend to become much more aware of those areas of evaluation which he must concentrate on to become more effective in his evaluation capabilities.

2. Videotape Monitoring of the Pilot Implementation Exercises

It was also learned during these pilot implementation exercises that the videotape replay of the completed exercise proved invaluable. It not only provided a tool to review the operational exercises, but it also became a mechanism for the student to observe himself in action.

3. Research Project Utilizing Empirical Data Collected During the Performance Measurement System Exercises

The types of exercises best suited for research purposes would most likely be equally well suited for enhancing training endeavors. The important goal in this regard would be to obtain a comprehensive data base. This can be best accomplished by having viable exercises on both BWR and PWR simulators which provide researchers with needed data in such areas as:

- Quantitative modeling of operator performance and reliability.
- Human factors aspects of control room design.
- Man-machine relationships that would contribute to the development of future control board designs.
- Personnel selection research.

4. Project Continuation

In conclusion, the proposed project continuation for implementing the Performance Measurement System for the next 3 years is divided into four tasks as shown below.

- Task 1: Develop 10 Additional Exercises for the Browns Ferry BWR Simulator
- Task 2: Develop 10 Performance Measurement System Exercises for a PWR Simulator
- Task 3: Adapt Exercises to a Second PWR or BWR Simulator
- Task 4: Conduct Research Projects Utilizing Empirical Data Collected During the Performance Measurement System Exercises

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SIMULATOR COMPARATIVE EVALUATION

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INTRODUCTION.

Tactical Air Command (TAC) requires simulation devices efficient in providing training in high-cost-of-training areas. TAC is currently evaluating simulation devices employing advanced visual, motion, and G-cueing subsystems procured to meet this requirement. This special project was conducted in order to establish base-line information regarding other simulator systems presently used in other government and civilian training capacities, and was directed verbally by the Commander, TAC. This effort provided an initial subjective evaluation of simulator systems presently available to the United States Government, Allied air forces, and airlines and under development by industry. This broad assessment of simulator systems and subsystems, which represent the state of the art in aircraft simulation, was conducted to provide TAC with the following:

a. An extensive listing of current devices and associated instructional features.

b. A detailed description of each system's/subsystem's capabilities and limitations.

c. A subjective assessment of the existing and/or potential ability of each system and/or subsystem to satisfy tactical air-to-surface (A/S) and air-to-air (A/A) training requirements.

d. Empirical data that will serve as an important part of the basis for a determination of simulator motion platform requirement.

The Simulator Comparative Evaluation was conducted by two evaluation teams (A/A and A/S). The teams evaluated the performance of 10 devices identified as having A/A training capabilities and 9 devices identified as having A/S training capabilities. In addition, 17 non-fighter-configured devices presently used in government/civilian training programs or research programs and 4 developmental systems were evaluated or observed. These systems represent a broad sample of varied visual and motion system combinations. Not all simulation systems worthy of TAC examination were included in this evaluation. Other advanced systems were identified as offering unique characteristics and capabilities but were unavailable during the time of this project. These systems, as they become available, will be examined in the future.

PURPOSE OF THE EVALUATION.

The purpose of this project was to subjectively evaluate the capabilities and limitations of current fighter-configured simulator systems to identify features that could enhance future A/A and A/S simulators. In addition, non-fighter-configured operational devices and certain systems in development were examined for features having potential application to tactical simulators.

The purpose was addressed specifically through accomplishment of the following four objectives:

a. Examine motion cues for positive/negative effects and the enhancement/degradation of pilot performance with and without motion platform.

b. Examine the capability of the various visual systems to provide the appropriate visual cues and references to perform selected tasks.

c. Examine the capability of the simulated flight characteristics to enhance training of selected tasks.

d. Identify the instructional features that will provide monitoring capability and control of specific situational training task inputs that enhance training effectiveness.

METHOD OF ACCOMPLISHMENT.

In preparation for the evaluation, a list of candidate simulators was screened by USAF Tactical Air Warfare Center (USAFTAWC),

TAC, and Aeronautical Systems Division (ASD) personnel. Some of the candidate devices were removed from consideration because of their similarity to other systems being evaluated, nonavailability during the evaluation period due to modification efforts or training schedules, or incomplete installation. Air attaches in England, France, and Germany were requested to recommend simulators in those countries that would be candidates for this evaluation effort. Only five foreign devices, all of which were in England, were recommended for evaluation. Two of these were developmental systems in industry, and three were training devices employed by the Royal Air Force (RAF). The candidate list of devices to be evaluated was categorized into groups of functionally common units or classes. The categories were (1) operational fighter-configured training devices, (2) operational non-fighter-configured training devices, and (3) engineering developmental systems. Following is a list of the devices that were evaluated or observed. The list is organized by category.

Fighter-Configured Devices.

F-14 (NAS Miramar, California)
TA-4J (NAS Chase Field, Texas)
Tornado Multirole Combat Aircraft (MRCA) (Warton, United Kingdom)*
Jaguar (Coltishall, United Kingdom)
Simulator for air-to-air combat (SAAC) Luke AFB, Arizona)
Large-amplitude multimode aerospace research simulator (LAMARS) (Wright-Patterson AFB, Ohio)
Large-amplitude system/wide-angle visual) simulator (LAS/WAVS) (Northrop Corp, Hawthorne, California)
Large-amplitude motion base simulator (LAMBS) (LTV, Grand Prairie, Texas)**
Vought air combat simulator (VACS) (LTV, Grand Prairie, Texas)
Motion base system (MBS) (McDonnell Douglas Corp, St Louis, Missouri)
Manned air combat simulator (MACS) 1/11 (McDonnell Douglas Corp, St Louis, Missouri)
MACS 111 (McDonnell Douglas Corp, St Louis, Missouri)
Advanced simulator for pilot training (ASPT) (Williams AFB, Arizona)
Differential maneuvering simulator (DMS) FTR (NASA Langley AFB, Virginia)
F-4 (RAF Coningsby, United Kingdom)
Buccaneer (RAF Honington, United Kingdom)
A-7D (Davis-Monthan AFB, Arizona)*

Non-Fighter-Configured Devices.

Boeing, Compuscene Visual (Seattle, Washington)
Boeing 707 (Link-Miles, Lancing, United Kingdom)
Redifon DC-10 (Crawley, United Kingdom)
American Airlines 727, Novoview Visual (Dallas, Texas)
American Airlines DC-10, Redifon Visual (Dallas, Texas)
United 737, Novoview Visual (Denver, Colorado)
TWA 707 VITAL 111 Visual (Kansas City, Missouri)*
Northwest 7X7 Link Mark V Visual (Minneapolis, Minnesota)*
Flying Tiger DC-8, VITAL 11 Visual (Los Angeles, California)
FSI DC-10, VITAL 11 Visual (Long Beach, California)
Southern Airlines DC-9 night visual system (NVS) (Atlanta, Georgia)*
Braniff 727, Duoview (Dallas, Texas)
Braniff DC-8, Novoview (Dallas, Texas)
Continental Airlines, Novoview 11 (Los Angeles, California)
NASA AMES (FSAA) Redifon Visual, Moffett NAS, California
NASA 737 (Langley AFB, Virginia)
C-135, Singer NVS (Wright-Patterson AFB, Ohio)
USN SH 2F, LAMPS (NAS Norfolk, Virginia)
S-61 Helicopter (NASA Langley AFB, Virginia)
USN S-3A, VITAL 111 (NAS Cecil Field, Florida)
USN P-3C Duoview (NAS Moffett Field, California)

Developmental Systems.

T-37/38 instructional flight simulator (Singer, Binghampton, New York)

*Not fully evaluated; demonstration only.
** Evaluated for motion simulation only.

Link NVS (Singer, Sunnyvale, California)

Calligraphic digital image generation (CDIG or DIGS) Singer, Sunnyvale, California)

USAFTAWC/TNA/TNS personnel examined and listed operational tasks to be performed during the evaluation missions in fighter- and non-fighter-configured simulators. Because of the limited access and time available, no more than four evaluation missions per pilot could be flown on each fighter-configured device and one mission per pilot on non-fighter simulators. Therefore, the emphasis was not placed on developing a complete list of operational A/A and A/S tasks, but rather an abbreviated list that was representative of tasks performed in A/A and A/S training. Twenty-four A/A tasks were selected and grouped appropriately into four sorties. The first mission consisted primarily of transition/formation tasks; the second and third missions included basic fighter-maneuvers (BFM), and the fourth mission addressed advanced air combat maneuvers (ACM). Twenty-eight A/S tasks were selected and organized into four evaluation sorties. The first mission primarily included transition maneuvers; the last three addressed tasks that included progressively more difficult ground attack events, complicated by weather restrictions when available. Each sortie/mission was designed to be accomplished in one hour or less. The missions were designed to maximize the opportunity for evaluation pilots to accomplish their subjective assessment of the capability of each training device and its instructional features. The non-fighter-configured simulators were examined by the evaluation pilots during only one mission. The tasks performed in the single evaluation mission included transition, instruments, and examination of limited visual field of view (FOV) application to weapon delivery.

In the development of the questionnaires, the four objectives that had been defined in the evaluation plan were found to be inadequate in categorizing all of the areas to be examined. Some cues to be examined were not clearly identifiable with any one of the four objectives; therefore, the questionnaires and the evaluation approach were structured around the following features:

Motion simulation
Visual cues
Target image (A/A only)
Flight characteristics
Sound cues
Special effects
Physiological effects
Instructional features/consoles
Overall training capability

Each evaluation team consisted of a project officer, three TAC fighter pilots as evaluation pilots, one briefing officer (pilot-qualified), one operations analyst, and an Air Force simulator technician. In addition, an ASD engineer accompanied the team to sites possessing a training device for which ASD did not have full descriptions. Basically, the responsibilities of the team members were as follows:

a. Project Officer. Each project officer was responsible for on-site evaluation management and conduct of the evaluation of each device.

b. Evaluation Pilots. The evaluation pilots were responsible for a subjective evaluation of the visual system, motion system, instructional features, and flight characteristics of each device evaluated.

c. Briefing Officer. The briefing officer was responsible for the detailed briefing/debriefing of each evaluation mission and for ensuring that a complete and detailed account was obtained from each evaluation pilot. The briefing officer also acted as the assistant project officer.

d. Operations Analyst. The operations analyst was responsible for ensuring that sufficient data were collected to satisfy the objectives of the evaluation and for processing the data in a manner that permitted expeditious analysis.

e. ASD Engineer. The ASD member was responsible for assessing each system's potential for engineering design advancements or improvements.

f. Simulator Technician. The simulator technician was responsible for developing a complete, detailed technical description of the system and

subsystems assessed during the evaluation.

The procedures used for systems evaluation were as follows:

The project officer preceded the remaining members of the evaluation team in order to obtain sufficient information to become familiar with the simulator's characteristics and operation. He then prepared a detailed briefing on the facility, which was given to the evaluation team and coordinated with site personnel to ensure that the simulator was properly configured for the evaluation.

The evaluation team members, upon arrival at the test site, were briefed by the project officer and provided with a familiarization tour of the facility. Whenever possible, the pilots were given an introductory orientation period in the flight simulator prior to flying the first mission. In most cases, the evaluation pilots were not qualified in the type of aircraft the simulator represented; however, they were all fighter-aircraft qualified, and reviewed the flight characteristics with qualified pilots prior to flying the simulator. All team members attended the premission briefing in which the briefing officer and operations analyst reviewed the requirements of data collection and the unique features of the device to be evaluated.

The project officer, briefing/debriefing officer, and operations analyst monitored the mission. The briefing officer and analyst exercised the instructional features and noted pilot comments during the course of the mission. The project officer ensured that the simulator technician had access to the necessary data and appropriate personnel to obtain sufficient system descriptions.

After completing each mission, the evaluation pilots completed their ratings and comments of the mission on the task questionnaire. All debriefing forms were reviewed by the debriefing officer and operations analyst for completeness.

A final debriefing was held at the conclusion of each system evaluation. All evaluation team members attended the debriefing, and every aspect of the system evaluation was addressed. A tape recording was made of the debriefing.

SUMMARY OF RESULTS.

The consensus was that current platform and beam motion systems evaluated do not provide effective cues or enhance realism for the performance of A/A or A/S tasks and enhance realism only in limited areas of transition maneuvers. The evaluation pilots felt that a sophisticated motion platform system is not required for tactical fighter training devices. Cues such as turbulence or runway feel were significant aids during instrument and transition tasks. Of the fighter-configured simulators, the simulator for air-to-air combat (SAAC), large-amplitude multimode aerospace research simulator (LAMARS), and Jaguar motion systems provided the most realistic cues for transition training; the differential maneuvering simulator (DMS) exhibited the most realistic buffet system.

The evaluation pilots estimated that the majority of all realistic motion sensations resulted from cues provided by effective visual systems. The computer-generated image (CGI) visual systems of the advanced simulator for pilot training (ASPT), TA-4J, and most airline simulators provided the most effective visual stimuli for altitude change, acceleration/deceleration, and rate and direction of turns. Simulators using dome projection systems, while providing good pitch and roll references, were less effective because of their apparent fixed position over the earth's surface.

Both evaluation teams agreed that an effective visual system, enhanced by optimized G-suit, G-seat, and buffet systems, would provide adequate cues for the performance of A/A and A/S tasks and these are required features for future fighter simulators.

Of the A/S systems evaluated, only CGI systems afforded the clarity and resolution necessary to recognize and identify objects at normal slant ranges.

Color proved to be an important factor for normal object recognition and identification in A/S training devices.

Small gaming areas increased the difficulty of performing A/S tasks by causing the pilots to expend inordinate effort to remain in the environment. Clarity, resolution, and gaming areas were generally

inadequate in all camera/model board visual systems.

Normal techniques and procedures could be employed only in simulators that duplicated the field of view of the aircraft.

The evaluation pilots concluded that unrealistic performance, size, and display of target aircraft degrade air combat training and that target images must allow determination of aspect angle, range, and closure at near-realistic ranges.

Simulator handling characteristics/flight performance that was not representative of the simulated aircraft detracted from the overall credibility of the simulator and represented a potential for negative training. Total fidelity throughout the flight envelope was not achieved by any of the devices evaluated; however, the DMS was rated as being faithful to the airplane's performance in most instances.

Cockpit weapon panels, switches, gunsights, or heads-up displays that are not identical to those of the aircraft being simulated and the lack of realistic integration of the complete weapon system detract from the credibility of the simulator and degrade training potential. Full weapon system integration was best demonstrated by the manned air combat simulator (MACS).

Special effects for A/A training, such as missile launch and impact indications and attacker's gun flash, were best demonstrated in the MACS. Special effects for A/S training, such as weapon impact indications and moving targets, were best demonstrated in the ASPT. Special effects for ceiling and visibility conditions in airline devices were better than in fighter-configured devices. Effective sound cues contributed to overall realism of missile launch and gun firing.

Of all the A/A devices evaluated, only the combined MACS I, II, and III systems demonstrated an interactive two-versus-one training capability. The evaluation pilots described this capability as being the most important requirement in future A/A simulation training.

None of the A/A systems evaluated featured console arrangements optimized to provide the instructor with adequate monitoring and control capabilities. The A/S systems having the best capability for instructor monitoring were the ASPT and TA-4J. Weapon scoring, aircraft parameter readout, and record/playback capability (in the ASPT) contributed greatly to the instructional capabilities of these systems.

Several of the airline training devices were considered outstanding in the areas of takeoff, approach, and landing. Features that were particularly effective in airline systems included excellent resolution and clarity of the visual scene; realistic night/dusk environment, which included horizon glow, moon, stars, and effective use of light points to represent the surrounding area; and excellent airport environment, which featured correct color for flashing and steady lights, runway texturing, runway detail, and landing lights. Additionally, some of these simulators have motion platforms optimized to provide takeoff and landing roll cues, runway feel, and effective acceleration and deceleration cues.

RECOMMENDATIONS. The following recommendations pertain to the requirements for future fighter simulators as determined by the evaluation pilots. The overriding consideration in making these recommendations was the enhancement of training capability. It is recognized that duplication of aircraft characteristics is impractical, if not impossible. For the areas addressed, the evaluation pilots felt that the actions indicated are necessary to prevent negative training.

Both A/A and A/S simulators should include the following:

G-seat, G-suit, and buffet systems optimized to provide acceleration/deceleration cues, zero- and sustained-G cues, buffet cues, and on-runway cues for systems that include takeoff and landing capabilities.

Visual presentations with sufficient content and detail to allow pilots to determine airspeed, altitude, and area orientation as they would in the aircraft.

Visual presentations that provide realistic grayout/blackout cues.

A sun image in all tactical fighter simulators.

An FOV that effectively duplicates that of the aircraft being simulated.

Correct simulation of the weapon systems complement, including aircraft radar and LCOSS.

Realistic simulation of aircraft flight performance throughout the flight envelope.

Realistic indications of weapon launch or release and end-game scoring (weapon impact point or missile hit/miss).

Appropriate sound cues for aircraft and weapons.

Instructional console features that include the following:

a. A "three-dimensional" view of the engagement/event.

b. Display of the pilot's view.

c. Repeated display of the LCOSS or HUD reference system.

d. Accurate weapon scoring and release parameters available in real-time and hard copy.

e. Ability to insert malfunctions and vary ceiling, visibility, and runway conditions rating for systems that include takeoff/landing training.

f. Voice and video record and off-line playback capability.

A/A simulators should include the following:

Interactive cockpits with 2VI capability with dissimilar aircraft.

Target performance and display that replicate, as nearly as possible, the aircraft represented.

Target portrayals of aircraft representing major threat categories.

Target image clarity, resolution, size, and detail that permit determination of aspect angle, range, and range rate at realistic distances.

Accurate simulation of fighter/adversary weapon firing envelopes and probability of kill.

Visual display with sufficient clarity, detail, and color for target acquisition and identification at normal/realistic distances.

An Iron Pilot (computer controlled target image) mode which utilizes realistic tactics, including Soviet defensive tactics.

Scheduling of training sorties to a maximum of 45 minutes.

A/S simulators should provide the following:

Simultaneous displays of multiple moving models such as SAMs, AAA, tanks, and trucks.

A realistic runway environment.

Controlled ceiling and visibility conditions and realistic breakout.

Gaming areas adequate in size to permit A/S tasks to be accomplished with normal procedures.

Realistic color depiction.

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THE JOY OF FLYING SIMULATORS

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INTRODUCTION

The problems of defining, designing, and developing flight training simulators and other synthetic ground-training devices are far exceeded by the problems encountered in their effective use. Their acceptance without pain by the entire aviation training and operating communities depends not only upon the further demonstration that they do work, but also that they can be integrated into a training program reasonably and painlessly. Indeed, it can and must be shown convincingly that they are the key to levels of operational effectiveness not attainable in training aircraft at any price, exposure to personal hazard, or potential equipment loss.

To do this, it will be necessary to sell "The Joy of Flying Simulators" that are defined and designed to teach and are not merely the products of the unfettered imaginations and budgets of simulator design engineers and marketing managers. The place for unfettered imaginations and budgets is in the development of new instructional technologies based upon the use of devices of unprecedented flexibility of programing and reliability of operation. Experiments recently completed at the University of Illinois for the Air Force Office of Scientific Research have demonstrated the economic and tutorial benefits of two innovative instructional technologies, interactive computer-assisted procedural training and automatically adaptive visual cue enhancement in the development of contact landing skills.

COMPUTER-ASSISTED PROCEDURAL TRAINING

Graduate student James P. Finnegan, supervised by Dr. Michael J. Kelly, measured the transfer of training of private pilots of limited instrument experience in flying holding patterns in varying wind conditions from the PLATO computer-based instructional system to the Piper Arrow airplane. Finnegan's CAI "simulator," originally developed by graduate student Stanley R. Trollip (1977), allows the student to "fly" a simulated airplane using a hand control with reference to dynamic instrument indications drawn by the computer on a plasma-matrix display screen.

Finnegan (1977) divided his 48 subjects into three equal groups who received the following training sequences: (1) CAI, then aircraft; (2) ground school, GAT-2, then aircraft; (3) ground school, then aircraft only, as a control basis for measuring transfer. CAI training proved comparable in transfer effectiveness to the analogous instruction in a Singer-Link GAT-2 general aviation trainer. In both cases there was reliable positive transfer, but at a big difference in cost, the interactive PLATO "simulator" being highly cost effective and the GAT-2 not being cost effective in this particular application. The applicability of CAI training, not only in flight procedures but also across the range of cognitive learning currently covered in ground school, warrants serious consideration.

ADAPTIVE PERCEPTUALMOTOR TRAINING

Gavan Lintern (1977), under my supervision, developed and demonstrated the transfer effectiveness of the substitution of automatic presentation and withdrawal of guidance cues in a simple skeletal computer-generated visual landing system in lieu of the verbal and manual assistance normally provided by the flight instructor during initial landing training. Lintern trained 48 flight-naive subjects to criterion landing performances in the Singer-Link GAT-2 without cockpit motion. Groups of 12 students each were trained under each of the following four conditions.

<u>Control Group</u>: All training by reference to a closed-loop, computer-generated skeletal airport scene consisting of a horizon, runway outline and centerline, and an aimpoint 500 feet from threshold, all TV-projected onto a spherical-section screen mounted in front of the pilot's cockpit.

<u>Continuous Augmentation Group</u>: Pretraining by reference to the same scene plus a visible representation of a desired flight path for the final approach, an extension of the runway centerline, and flare cues represented by inverted L-markers placed along either side of the runway starting 2,000 feet from threshold.

<u>Adaptive Augmentation Group</u>: Pretraining by reference to the same augmented visual scene, with the exception that all augmented guidance cues were automatically withdrawn whenever the simulated airplane was within specified tolerances relative to the desired flight path, thereby weaning the students of

the nonreal world assistance and comfort they afforded.

Transfer Control Group: An equal amount of pretraining by reference to a projected cross representing the airplane's actual flight path and a projected square representing the desired flight path, thereby creating a compensatory tracking task and controlling for the possible transfer of learning associated uniquely with practice in controlling the simulator.

Following their pretraining, each of the three transfer groups continued training to criterion performance levels under the control condition. All students in all groups reached the criterion of three successive landings within preestablished tolerances, and the transfer effectiveness of the three experimental pretraining strategies was in the predicted order: The group with automatically adaptive augmented visual feedback reached criterion most quickly; the group with continuous augmentation during pretraining was next; and the group that practiced making approaches without benefit of any representation of a dynamic airport scene showed little transfer, if any.

One subject from each of the four groups was given one preexperimental flight in a Piper Arrow during which he was allowed to attempt six approaches and landings. Of the total of 24 attempts, none was successful; in all cases the instructor had to take over control. Subsequent to the simulator training, 21 students drawn randomly from the remaining 44, in approximately equal numbers from the four groups, were similarly tested in flight, and 29 of the 126 attempted landings, an average of 1.38 per student, were made without assistance from the instructor and without any previous flight experience.

CONCLUSIONS

It is evident that continued training to a criterion of three successive unassisted landings in the airplane by students previously trained to criterion safely and painlessly in a relatively inexpensive simulator with a simple visual system would result in extremely high transfer of perceptual motor skills required in contact flight. Furthermore, it appears that more can be gained by imaginative, inexpensive, and enjoyable instructional strategies, such as automatically adaptive cue enhancement and performance feedback, than can be gained by any investment in visual systems of high literal image fidelity. Similarly, the application of computer-assistance to procedural training, regulatory currency, and cognitive refreshment is cost effective and more fun than ground school.

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HIGH-G SIMULATION - THE TACTICAL AIRCRAFT SIMULATOR PROBLEM

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SUMMARY

The platform motion system has been the principal motion and force simulation device in the past and over the last five years the G-seat, G-suit, and seat shaker systems have become a part of several of the Air Force's simulators. This paper presents the background behind the development of these devices and a discussion of current and future non-visual system motion and force developments. The challenge of providing high acceleration cues for the tactical aircraft simulator pilot is presented by first, looking at the need for high-G simulation and second, looking at the current development of an advanced G-cuing system, high-G augmentation devices, and bionic means for controlling simulator visual displays.

INTRODUCTION

A considerable body of literature exists concerning the physiological responses of humans exposed to high linear accelerations. The emphasis in much of this earlier work, as reviewed by Fraser (1), Roth (2), Gillies (3), and McElhaney et al. (4), is on the protective measures required to permit subjects to survive transient or sustained high acceleration stimuli and, if possible, to continue performing as pilots. The impact acceleration studies have concentrated on the biomechanical responses and have led to the development of a variety of safety mechanisms. Similarly, the long duration acceleration problem has concentrated on the cardiovascular effects and has led to the development of several G-protective devices, most notably the anti-G suit to prevent pooling of blood in the lower thorax and legs. Research facilities used for these studies have typically been the shaker or deceleration sled for brief duration studies, and the centrifuge for long duration studies. The centrifuge has been used as a way of exposing research subjects and pilots expected to undergo sustained long duration high-G forces (such as astronauts preparing for reentry).

As a simulation tool for training of pilots in practical aircraft, however, the centrifuge has obvious limitations because of the development of very strong erroneous cross-coupled angular acceleration and Coriolis cues during rapid maneuvering, as well as the economical impact of their regular use. Consequently, there exists a clear need with the development of newer tactical aircraft which will develop higher G-forces to find some way of simulating at least some of the effects of these forces on the pilot in order to assist in both the validity of the training and preparation for actual experience in flight.

The principal physiological system responses to plus-G (eyeballs down) sustained acceleration are attributable to biomechanical affects on the skeletal system and cardiovascular responses. The well-known cardiovascular responses are attributable to the hydromechanical forces on the circulation, which produces a relative pressure drop in the circulation varying with height above the heart. The consequences are a gradual draining of blood from the cerebral circulation and the upper body, and a pooling of blood in the abdominal region and in the legs. The most prominent and well-known sensory effects are the visual ones, in which a gradual narrowing of the visual field occurs as delivery of oxygen to the retinal circulation of the periphery is reduced, resulting in an increasing tunnel vision and finally complete blackout which may eventually be followed by unconsciousness. The related cardiovascular responses are associated with the compensatory mechanisms in the system, adjusting cardiac output and heart rate to the new circulatory demands.

The principal biomechanical events noticed by the pilot are, of course, the increase in direct pressure under all supported

parts of his body, especially the buttocks and back in a seat, and a tendency for all unsupported parts to be driven "down," requiring a fatiguing increase in steady state muscle tone just to maintain posture. In particular, the unsupported head tends to be rocked back slightly for the typical pilot seat position with the back rest tilted back away from the $+g_z$ vector. The arms, hinged at the shoulder and elbow, are driven down toward the feet, unless they are supported by arm rests and use of a type of side arm controller, in which case there is a pressure buildup under each limb segment. Both total force on body segments and the spatial distribution of such forces are important acceleration cues. As the subject is driven down into his support and the fleshy tissue is compressed, different tactile sense endings come into play. Additionally, changes in the field of view are noted as the pilot's eye position is depressed in the cockpit. The direct biomechanical effect of positive G forces on the respiratory system is in the production of forces on the rib cage which interfere with inhalation and make breathing shallow and labored.

Although a number of other physiological responses to positive acceleration have been identified, the ones referred to above appear to be the most significant from the point of view of simulation for tactical aircraft training.

MOTION AND FORCE SIMULATION DEVELOPMENT

A fundamental control process in which all humans engage is the control of the static and dynamic state vector of their bodies. From seemingly rudimentary skills, such as learning to crawl, to complex tasks such as controlling the activity of powerful and/or high-speed transport machines in which he rides, man employs a remarkably clever set of physiological sensors to maintain his safety and sense of well-being while accomplishing the state vector change he desires. Man learns to discriminate among the physiological stimuli presented him in order to define and refine his perception of bodily motion, and then uses this assessment to modulate his control action. He not only continually mediates the stimuli normally available to him for bodily motion perception, but also likely develops magnitude associations based on variations in the composition of stimuli perceived.

Platform Motion System

The perception of bodily motion is considered important in learning to pilot an aircraft. Hence, in aircraft simulation, the art of providing this perception, motion cuing, is a simulation discipline in itself. The majority of this discipline has centered around attempting to subject the pilot trainee, plus total simulated cockpit, to a reduced-scale semblance of the accelerations associated with the actual aircraft and task. Force-producing devices (motion systems) similar or identical to the device pictured in Figure 1 are employed to present these accelerations as well as provide cues concerning static body spatial orientation. The presentation occurs in all six degrees of freedom and has met with some acceptance, particularly in the simulation of transport aircraft, where translational and rotational accelerations are normally low and aircraft attitudinal changes are normally confined to extremes which do not exceed the motion attitudinal capabilities by more than a factor of two or three (5). The Air Force is currently not including platform motion systems for the A-10 and F-16 simulator programs.

The single strongest asset of a motion system is that once in the simulated cockpit, the pilot is presented with a force and spatial attitude generation system which, in terms of visual appearance, usually is entirely faithful to that existing in the actual task. Simulation engineers working closely with pilots note that such visual environmental fidelity seems important toward enabling the pilot to "slip" into believing he is in the actual task so that he will react in the same manner as in the actual task. Visual environmental fidelity is afforded by the motion system because the total cockpit and pilot are moved, and thus vestibular response is excited through the same mechanism as in the actual task, pilot/cockpit inertial coupling exists, and associated somatic sensation occurs naturally without artificial devices. Unfortunately, motion systems are constrained by the necessary physical limitations placed on their size (6). As the dynamic range of the desired force sensation increases and/or the duration of desired force application increases, these limitations become more apparent in the simulation. For medium-performance tactical aircraft simulation, the motion system simulation engineer must make increasing use of onset cuing plus subsequent washout, wherein only the leading edge of the simulated aircraft acceleration is presented to the pilot trainee, followed by a low-level period wherein velocity and excursion capability expended during the onset is recaptured in preparation for the next cue. The crux of the simulation engineer's dilemma

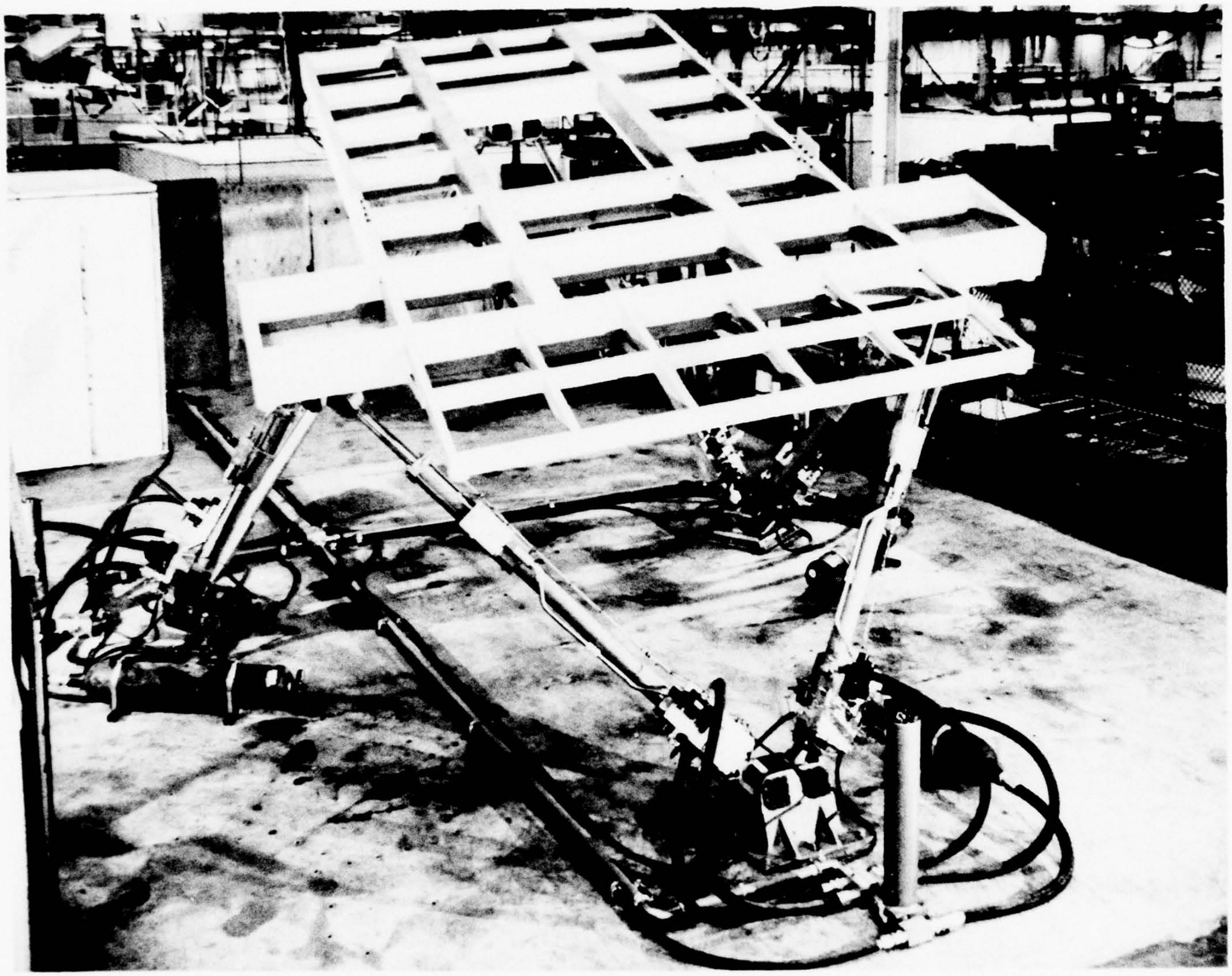

Figure 1. Six Post Platform Motion System - Link Division of Singer

is that as he tries to increase the duration of force application, the permitted cuing dynamic range decreases, and vice-versa.

The dilemma arises because in moving from transport to tactical aircraft simulation, both desired force duration and dynamic range increase. Under these conditions it is reasonable that stronger, more pronounced physiological perceptions should be available to the pilot from the somatic sensory system owing to stronger body/cockpit inertial coupling. Should both acceleration duration and magnitude become even larger, as in the newest tactical aircraft, the frequency of occurrence of physiological effects associated with high-G conditions is likely to be more prevalent, and it is not unreasonable to extrapolate that these perceived effects will find their way into the control patterns employed by the pilot. It is apparent, then, that the physiological conditions desired within the simulation begin to outdistance the capability for cue production through utilization of the motion system alone. However, the motion system appears to have a useful range for physiological stimuli production beyond which additional devices must be brought to bear.

G-Seat

The Air Force Human Resources Laboratory recognized this fact in the late 1960's during the study phase preceding the Advanced Simulation in Undergraduate Pilot Training (ASUPT) contract. A commonly accepted conclusion at that time was that in pursuing the development of force stimuli simulation devices ancillary to the motion system, first importance must be given to the accurate reproduction of somatic stimuli associated with the effects of acceleration in the 1 to 3 G-range; simulation of induced visceral effects attendant with higher acceleration regions would follow at a later point in time. The logical candidates for somatic stimulation were those physiological systems which could be addressed through pilot seat alteration, since there was a reasonable chance to maintain good cockpit visual environmental fidelity if the simulation was confined to the seat itself. Further, it is quite apparent that a large part of the somatic sensation in the actual aircraft occurs in the buttock/back region as a result of pilot/seat inertial coupling effects.

Link Division of the Singer Company developed the G-seat (7) pictured in Figure 2 under the ASUPT contract for the express purpose of determining the adequacy of simulating tactile, pressure, and skeletal stature stimuli associated with flight-induced body G loading. The approach selected involved construction of seat cushions composed of mosaics of elements in which the elevation of each is individually controlled by the drive philosophy programmed into the simulator's computational system. It is therefore possible to change cushion attitude, elevation, and shape with the same mechanical system. The G-seat employs a variable-tension lap belt to apply pressure stimuli in the ventral area of the pilot during negative G and/or braking conditions, the G-seat drive philosophy developed by Link primarily addresses the skeletal attitude shifts and their impact on eyepoint perspective, head/neck bobbing, and flesh scrubbing as well as localized flesh pressure changes and tactile perceived area-of-flesh/seat contact changes associated with sustained G conditions. Experimentation with this seat indicated that not only were the sustained G stimuli presented by the seat employed positively by pilots in the control of the simulated aircraft, but in moving from one acceleration magnitude to another, a form of acceleration onset information was provided to the pilot. The two ASUPT G-seats were the first of ten similar "First Generation" G-seats built or currently under construction for use by the Air Force and Navy. During this period, the value of the G-suit as a G-cuing device has become more broadly appreciated.

G-Suit

The G-suit cue represents an excellent example of apparent pilot G-level assessment by way of association. G-suits are employed in tactical aircraft to counter blood pooling in the lower extremities during high-G conditions. Providing external pressure to the lower extremities, the suit restricts the blood from settling under inertial forces and thereby maintains more normal blood pressure conditions at the heart level and, more importantly, retards blood starvation at the elevation of the brain, thereby extending either G-level range or exposure time prior to loss of vision and subsequent unconsciousness. A predominant early perception experienced by the pilot, well before any visceral effects materialize in vision, is a tactile perception associated with the pressure induced by the G-suit. The pilot appears to associate this perception with increased G loading. Providing a similar experience within the simulation by inflating operationally issued G-suits according to the simulated flight G loading produces a very strong G loading cue for pilot utilization. Equally important is the fact that this cue is made available by a device

Figure 2. First Generation G-Seat (Backrest Bellows Exposed)

which is present in the actual task, and, therefore, visual environmental fidelity is maintained within the simulation.

Seat Shaker

Coincident with G-seat and G-suit utilization, seat frame shaker systems have been developed to provide vibratory cues in the frequency range beyond that readily obtainable with cockpit motion systems. Vibratory cues are a part of the force environment somatically monitored by the pilot and used within his control patterns. Much as any large machine, an aircraft "talks" to its pilot through vibratory means, providing information concerning its operation and its status within the realizable flight envelope. In terms of G-cuing systems, if the motion system is labeled the low-range device, the G-seat, suit, and shaker systems would be considered mid-range G-cuing systems.

Limitations and Ranges of G-Cuing Devices

The successful introduction of the G-seat within the tactical aircraft simulation environment has been an extremely significant milestone in terms of mid-range G-cuing. However, just as the motion system has its limitations, so does the G-seat. As previously mentioned, the G-seat confines its physiological stimuli production to the pilot/seat inertial coupling area. It makes no demands upon the pilot other than to sit in the seat and buckle the strapping used in the seat and in the actual aircraft, thereby maintaining visual environmental fidelity. As a consequence of this approach, pressure buildup in the back/buttocks area is limited to that available from the 1-G weight of the subject himself as modulated by variation in the shape of the flesh-supporting surface. Neck muscular stimuli associated with G loading of the helmet and head are limited to those available by changing the attitude of the torso so that the 1-G gravitational weight of the helmet/head loading varies neck load. Head bobbing through interplay of skeletal structure and cushion surface attitude is limited to that range of attitudinal change permitted as complementary by the somatic senses of the back/buttocks area. Inertial load buildup in the arms is not directly addressed. Visceral effects and their perceivable by-products are ignored altogether. Yet as the dynamic range of aircraft acceleration increases, as it has with the introduction of advanced fighter aircraft, it is not unreasonable to hypothesize that future force simulation systems must include some of these high-G effects.

The development of kinesthetic cuing devices can be likened to the development of a speaker system. As the range of information to be transmitted increases or its composition changes to include new pieces of information important to be heard, the transmission device must be altered. In some cases the device is designed to address specific characteristics and cannot adequately cover the complete spectrum of information to be transmitted. In speaker technology the answer has been to employ different speaker designs in the area of their respective merit but collectively as one integrated system: low-range woofers, mid-range speakers, and high-range tweeters. A corollary may exist in kinesthetic cuing devices when examining the merits and limitations of motion systems and G-seat systems. Advanced fighter aircraft extend and change the composition of kinesthetic cues to be delivered. The high-G augmentation devices discussed herein may be considered as independent operators and would be designed to provide specific sensations. Their true merit, however, lies in extending the spectrum of information transmission when used in conjuction with G-seats and motion systems.

ADVANCED G-CUING SYSTEM DEVELOPMENTS

Advanced Low Cost G-Cuing System

The introduction of the first generation G-seat to the tactical aircraft simulation environment demonstrated the apparent potential for inducing valuable kinesthetic stimuli via a direct approach to the somatic sensory system. However, questions arise as to whether the mechanical capabilities of the first generation G-seat optimally exercise this potential and extract a maximum benefit from this cuing source. Can improvements in selected areas increase the cuing yield and if so, what areas and what type of improvements should be considered? In 1975, the Air Force released a specification defining G-seat requirements for future G-seat procurement. Additional G-seat research is required to establish a baseline system reflecting optimum performance capabilities. These capabilities would then be included within and modify the specification controlling G-seat procurement.

One point of particular concern in any cuing system has been system response (8). The first generation G-seat employs a servo system of approximately 1 Hz bandpass. Initially, a fairly low software iteration rate in the 7 1/2 - 10 iterations/second

range were employed to drive the G-seat. Although under certain sharp maneuvering conditions there is occasional pilot comment noting apparent time delays in the seat system, it is not known whether this is purely a consequence of the iteration rate or whether improved hardware response would be of material benefit. Iteration rate alteration research at the installations currently employing G-seats is not easily accomplished. Facility computational capability constraints are encountered because the iteration rate to be altered is not only the G-seat software but usually the complete flight dynamics package as well. To establish the most beneficial response requirements, it is advisable to employ a computational facility within which flight dynamics and G-seat software can be cycled at rates in excess of that thought to be the maximum required and employ seat hardware possessing high response characteristics. In this manner, full system capability can be degraded to determine that point at which further degradation produces adverse and noticeable system delays.

The first generation G-seat was designed to provide a sensation of sustained acceleration and employs a cuing philosophy which does not make use of transient onset cuing (7). This approach has been well received as a sustained cuing device and, somewhat unexpectedly, it was found that a measure of onset cuing is overtly experienced as a byproduct of the sustained cuing philosophy. Nevertheless, ongoing work in sensory systems modeling indicates that improved kinesthetic cuing should be attainable through more sophisticated transient cuing drive schemes. Again, it is desirable, when considering transient motion, to employ highly responsive hardware as the initial starting point and experimentally degrade the response to that level wherein transient cuing concepts are noticeably and adversely affected.

With the foregoing in mind, the Air Force Human Resources Laboratory concluded a G-Cuing System research test bed was required and in mid-1976 awarded Link a contract for the development of an Advanced Low Cost G-Cuing System (ALCOGS) embodying certain specific objectives:

1) Bring seat, suit, and shaker together as one integrated system with common control.

2) Improve the response characteristics of primarily the G-seat, and secondarily the G-suit, over those existing in today's operational seat/suit systems.

3) Provide closed-loop servo operation so that accurate means to measure system capability expended to produce a given cue can be monitored.

4) Investigate, develop, and embody within the final system mechanical concepts which improve the somatic cuing quality of the G-seat over that available in the first generation of G-seat approach.

5) Broaden the resultant hardware and software design to accommodate F-16-type tiltback seat configurations as well as the more conventional upright seat configurations associated with the F-15 and other aircraft.

6) Attempt to design this system so as to lower the aggregate cost of a seat/suit/shaker system.

7) Build and deliver a system with the above characteristics as well as a software drive module for Air Force research.

The ALCOGS system has been designed and is currently under construction. An artist's rendition of its seat configuration is provided in Figure 3. The most noticeable changes from the first generation G-seat are:

1) The departure from a mosaic element cushion approach, but the retention of cushion attitudinal and elevation change capability.

2) The implementation of thin cushion surface bladders for localized pressure and tactile area-of-contact stimuli generation.

3) Hydraulic actuator servo systems to provide the desired response characteristics.

4) Adoption of passive rather than active seat pan thigh panels.

5) The implementation of lower backrest radial elements to provide strong area-of-contact cues for vertical and longitudinal acceleration.

6) Differential lap belt drive for inclusion of lateral as well as longitudinal and vertical belt cuing.

7) The addition of a seat pan longitudinal degree of freedom cascaded on seat pan cushion pitch roll and heave.

The ALCOGS G-seat cushion assemblies are

Figure 3. Advanced Low-Cost G-Cuing System (Artist's Concept)

mounted in a replica of the F-15 seat frame which in turn is mounted on a test bed frame which can either be inserted in a T-38 cockpit or left free standing external to the cockpit. The seat frame is supported on the test bed frame by linkages which permit the seat to be oriented at any angle of inclination between that employed by the F-15 and F-16 seats. The seat frame is pinned to the test bed so as to permit the frame to be vibrated by a seat shaker actuator at $\pm$ 1/2 G in the 4.5 - 40 Hz range. Buffet and other vibratory effects may be displayed by the seat frame shaker or, alternately, the seat pan cushion itself. The suitability of the latter will determine if the role of the seat frame shaker may be absorbed by the G-seat and the seat frame shaker system eliminated from future G-Cuing Systems.

The G-suit features a press-to-test and pressure/G instructor input which are handled all-electronically rather than by mechanical and software means, respectively. A high volume pneumatic servo valve design serviced by compressed air and vacuum provide more rapid suit pressurization and exhaust than that available, for example, in the Simulator for Air-to-Air Combat (SAAC) and F4E18 G-suit installations.

Similar to many motion system installations, the G-Cuing System is supported by an electronics control cabinet which houses the electronics associated with system control logic and the sixteen servo loops. The Electronics Control Cabinet permits system operation in a "maintenance" mode wherein the G-Cuing System servos may be driven manually, or by two software drive modes: one wherein system control is maintained at the location of the electronics cabinet and a second wherein system control is transferred to a remote location such as a simulator instructor/operator station. The electronics cabinet employs two variable frequency oscillators to permit the generation of superimposed vibratory effects at any frequency in the 4.5 to 40 Hz region. A discrete "bump" channel is further superimposed upon the vibratory output. The electronics cabinet also controls the activity of the G-Cuing System pumping station wherein hydraulic, pneumatic compressor, vacuum pumps, and associated reservoirs are located.

Primary design problems centered in the G-seat system and in two areas: system response and packaging. Two G-seat design objectives called for seat pan and backrest cushion excursion of 2-1/2 inches and a rise time of all servo actuators of 30 ms or less. The latter implies a system bandpass of 10 Hz or an order of magnitude larger than that available in the first generation G-seat. The bandpass objective advocates the utilization of hydraulic actuators and, to ensure that hydraulic resonant frequencies are maintained well above the bandpass frequency, servo valve mounting in close proximity to the actuator. The servo valve/actuator selected meets the 10 Hz bandpass objective.

Even more challenging, the same 30 millisecond rise time objective was sought in the cushion pneumatic surface bladders (firmness bladders) overlaying both seat pan and backrest cushions. A dual compartment (right and left) bladder is employed on the seat pan and a single compartment bladder employed on the backrest. Although only approximately one inch thick when inflated, these bladders represent significant volumes. Based on the function of the bladders, pressure and tactile area of contact stimuli generation induced by depressurization and resultant flesh contact with the undersurface supporting the bladders, it was felt the driving medium must be air. After considerable searching and testing, a two stage pneumatic servo valve assembly was developed which can handle the large air volume at the desired 30 ms rise time objective.

It is apparent that the response design objective required the utilization of servo actuators considerably more mechanically sophisticated than that employed in the first generation G-seat. System cost reduction could be realized, therefore, only if the cushion assemblies could be packaged in such a manner as to permit a broad application to many different seat styles with minimum redesign. A design objective then was to package the cushion assemblies within volumes commensurate with that extant in standard survival kits and parachute packs. This task was made difficult by the number of actuators employed, the fact that these actuators are hydraulic, the desire to keep actuator and servo valve in close proximity to one another, and the 2 1/2-inch cushion stroke requirement coupled with ram end cushion capability. The resultant design packages five servo systems in a backrest assembly which is approximately 15 x 21 x 3-3/4 inches in dimension. The seat pan assembly packages six servo systems in a volume approximately 15 x 15 x 6 inches in dimension. A modular design approach has been employed in the actuator assemblies themselves in order to permit actuator set up and service.

The ALCOGS system will be integrated with the Wright-Patterson AFB Human Resources

Laboratory Simulation and Training Advanced Research System (STARS) complex and it is expected that G-cuing research will commence utilizing this system prior to the end of 1977.

High-G Augmentation Device Study

As mentioned earlier, the G-seat may be considered a mid-range G-cuing device. Newly developed tactical aircraft exercise a flight regime wherein high-G loading is more often experienced and the physiological stimuli associated with this condition may gain importance in aircraft maneuvering control patterns. Based on this, it is appropriate to commence consideration of the types of simulator systems which might provide high-G effect stimuli.

A combined Human Resources Laboratory/Massachusetts Institute of Technology/Link effort is currently studying potential force simulation systems in an attempt to identify those systems which:

a. are likely to produce a stimuli important to high-G maneuvering control and,

b. appear to be able to generate stimuli artificially in a 1G environment by means acceptable to operational pilots.

The current effort is strictly a study leading to characterization of the type of hardware/software systems required to produce the desired end effect. The system characterization is to form the foundation for eventual construction of experimental systems to determine the adequacy and usefulness of the simulation stimuli source.

The study will attempt to set forth the most reasonable methods of generating G loading stimuli in the following areas:

a. Shoulder harness

b. Head/helmet coupling

c. Limb loading

d. Aural effects

e. Visual effects

The effort in addition to addressing the above specific areas will investigate the potential of stimuli production via some of the following methods:

a. Body negative pressure

b. Respiratory control

c. Lacrimation control

d. Flesh pressure/temperature interrelationships

Bionic Control of Simulator Visual Displays

Bio-feedback techniques are also being considered for the tactical aircraft simulator pilot. The University of Dayton is currently developing for the Air Force a method for bionic control of the simulator cockpit visual environment.

The objective of this effort is to improve a technological deficiency which currently exists in training simulation. Gravity effects are simulated in ground-based trainers via motion systems, G-seats, G-suits, seat shaker systems, and visual cues. All of these G-cue effect devices have their strengths and weaknesses. This effort will address the gravity effect produced by current visual simulation systems. State-of-the-art training devices have the capability for dimming the visual display of the simulator as a function of positive G. This effect simulates the loss of vision pilots sometimes suffer under high, positive acceleration. The Simulator for Air-to-Air Combat (SAAC) is a good example of this technology. The problem with this simulation is that the pilot has no physiological control over the (1) intensity and (2) onset of this dimming in the SAAC. He cannot, for example, perform the M-1 maneuver and eliminate the dimmed display; he has no direct means of affecting the display in the simulator other than changing angle of attack, etc. In the actual aircraft, however, the pilot can control the loss of vision through the M-1 maneuver. The purpose of this effort is to develop a means by which pilot straining, via the M-1 maneuver, can be sensed and used in the total simulation control loop to drive the dimming level of the visual display as a function of G. Such a development should enhance the tactical air combat simulation and provide valuable training in pilot energy management.

This effort encompasses the design and development of a software program and associated hardware for the bionic control of acceleration induced dimming of the simulator pilot's visual display. To accomplish this, two algorithms will be developed. One will be a dynamic algorithm of the human visual system which will be driven by the pilot's G-environment. The other will be an algorithm to predict the effectiveness of the pilot's M-1 maneuver, which will be driven by electromyographic potentials from selected muscle

groups. The outputs from these two algorithms will be integrated to drive a brightness controller for the visual display. The integrated system will be implemented at the AFHRL STARS facility on the T-38 simulator. If successful, the system may be implemented on the SAAC, UPT-IFS, and other Air Force simulator programs.

CONCLUSION

The successful introduction of the G-seat within the tactical aircraft simulation environment has been an extremely significant milestone in terms of mid-range G-cuing. However, just as the motion system has its limitations, so does the G-seat. With the possibility that the A-10 and F-16 simulators will have no platform motion systems, the Air Force Human Resources Laboratory is performing the research and development of other means of full-range G-cuing. High-G augmentation devices are being designed to provide those specific sensations characteristic of fighter/attack aircraft. An advanced G-cuing research system has been developed which can address the A-10, F-15, and F-16 motion and force simulation problems. However, the true merit of these and other devices lies in their ability to match the spectrum of kinesthetic cues delivered in advanced tactical aircraft.

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OBJECTIVE AND SUBJECTIVE EVALUATION OF THE EFFECTS OF A G-SEAT ON PILOT/SIMULATOR PERFORMANCE DURING A TRACKING TASK

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ABSTRACT AND SUMMARY

A seat cushion to provide acceleration cues for aircraft simulator pilots has been built, performance tested, and evaluated in NASA Langley's Differential Maneuvering Simulator. The four-cell seat, using a thin air cushion with highly responsive pressure control, attempts to reproduce the same events which occur in an aircraft seat under acceleration loading. The pressure controller provides seat cushion responses which are considered adequate for current high-performance aircraft simulations.

An experiment was designed to evaluate the effect of the g-seat on pilot/simulator performance. The statistical analysis of data indicates that the pilot gets information from the seat which allows more precise control of the simulated aircraft. Pilot subjective data support the conclusions of the statistical analysis.

Introduction

In the control of an aircraft, the kinesthetic cues or "seat-of-the-pants" feel provide important information to the pilot concerning the aircraft's dynamic state. Pilots sense such kinesthetic cues as buffet, control forces, and linear and angular accelerations. One of the most important of the acceleration cues is the normal acceleration. Under positive normal acceleration, the pilot is subjected to an increase in weight for each part of the body. This results in such things as the blood pooling in the lower portions of the body and a reduced blood flow to the head which eventually results in tunnel vision and blackout. (Reference 2). The increased body weight also causes increased pressure on the "seat-of-the-pants" as the seat cushion padding becomes fully compressed and no longer conforms to the pilot's buttocks. This causes a greater portion of the pilot's weight to be borne by the area around the tuberosities (the two bones which protrude furthest into the buttocks) and thus a change in the pressure distribution on the buttocks.

There are other acceleration cues such as heaviness in the extremities; however, the "seat-of-the-pants" feel seems to be one of the most noticeable. In view of this, a seat cushion was designed and built to reproduce these pilot sensations in an aircraft simulator. This paper describes the approach to the cushion design, the seat transfer functions, and the design of an experiment to discriminate between pilot performance with and without the seat cues. The statistical analysis of the data and pilot opinions concerning the realism of the seat and its value as a performance aid are presented.

Seat Cushion Design

The objective in building the simulator seat cushion is simply to reproduce as nearly as possible the same events which occur in the aircraft seat. In order to compress the seat padding as if the pilot weighed more, air with pressure control is used as the padding material with a non-compressible surface (wood) underneath the air cushion. The basic design is shown in Figure 1.

The seat is initially biased such that the air conforms to the pilot to support most of his weight as shown in Figure 2. The initial air pressure allows the two main support areas, the tuberosities, to touch the wood surface and thus begin to compress the flesh near these areas. Thus, the bias adjusts the "firmness" of the seat. Then as accelerations increase (positive g) air is removed from the seat giving the effect of compressing the cushion material and causing more of the pilot's weight to be supported by the area around the tuberosities. However, some air is left in the seat to prevent the false cue of the seat falling away from the sides of the legs and buttocks. For negative g, sufficient air is added to seat to remove all contact with the wood and thus uniformly support the body weight, without becoming firm due to too much air.

This manner of seat operation (i.e. reproducing the aircraft seat actions) automatically reproduces other related pilot events as raising or lowering the body which results in changing the eyepoint and the joint (hips and knees) angles.

The full seat design (Reference 1) is shown in Figure 3. The air cushion is made of pliable rubber and has four air cells per seat and back cushion with individual pressure controllers for each of the eight cells. This allows differential control to "tilt" the seat pans for various cues. The air cushions are 2.54 cm (1-inch) thick to minimize "following" as the pilot shifts his weight and to increase response time by

lowering the air volume required. The "following" occurs when the pilot moves in such a manner to remove a part of his buttock area from contact with the seat. The constant air pressure would cause the seat cell to "follow" the moving area until the seat reaches the limit of its excursion capability. In this case, the maximum "following" would be 2.54 cm (1-inch) or less.

Pressure Control

The inherent design of the seat requires precise and responsive control of the air pressure in each cell. Therefore, the servo controller utilizes pressure feedback as shown in Figure 4. The design uses large air lines (3/4-inch ID) and locates the pressure transducer at the air cell to get true seat cushion pressures as shown in Figure 5. The air control valve used is a standard aircraft anti-g suit valve with the normal activating slug replaced by a motor which provides the linear actuation of the valve as shown in Figure 6. The aircraft valve was chosen because it provides adequate pressurization time and, more importantly, adequate bleed time without the use of other devices such as booster relays which tend to degrade the pressurization time. The valve has a non-linear relationship between the input displacement and the output pressure, however, the pressure feedback provides linear response.

Seat Cushion Response

In the design of the servo controller, it was considered important for the seat to follow the command with minimum time lag in order to be able to respond to the aircraft dynamics. It was also desired to closely match the seat response with the simulator's visual display response. The design of the seat requires a decrease in air pressure (and, consequently, more of the pilot's buttock area contacting the hard surface) for positive g; therefore, the removal of air from the seat is the most important and most difficult to achieve due to the low-pressure differential. Figure 7 shows a pressurization time (decreasing g) of 45 milliseconds and a bleed time (increasing g) of 60 milliseconds for a 50% step. Both positive and negative steps have settled to within 10% of the final value in 100 milliseconds. Analysis of the step and sinusoidal responses show that the system is essentially a .45 damped, 25 rad/sec, second order system over the range of 0 to 8 Hz. This provides a 35 millisecond time lag from seat command to seat pressure over the seat's full range of operation. The dynamic response data is summarized in Table I.

Drive Signal Development

A complete seat pan was installed in NASA Langley's Differential Maneuvering Simulator (DMS), Figures 8 and 9, which is described in Reference 3. The DMS has a wide F.O.V. visual display where all servos involved in projecting the visual scene are synchronized with a .7 damped, 25 rad/sec, second order transfer functions. The initial step in the development of the complete seat drive signals was to drive the seat pan with normal acceleration. Additional terms for other cues are to be added one at a time. For the normal acceleration drive, the seat cells were subjectively scaled using 6 LRC test pilots and 2 engineers. The scaling (Figure 10) was developed by the test pilots and engineers making comparison flights in the LRC T-38 aircraft. Note that the two forward cells are driven over a smaller pressure range than the two rear cells. This is due to the fact that the pilot's feet, resting on the rudder pedals, do not allow his upper legs to fall as his torso does. Also note (Fig. 10) that no cells are driven to zero differential pressure in order to prevent the false cue of the seat falling away from the pilot's legs and sides of the buttocks. The scaling chosen allows maximum "feel" at +6g and 0g with the 1g neutral position biased (as a function of pilot weight, Figure 11) to allow the pilot's tuberosities to just contact the hard surface as described earlier. This scaling was found to give good pilot sensitivity to small "g" increments while performing tracking tasks as well as providing good overall feel at the maximum "g" levels.

Initial Performance Tests

Following the scaling of the normal acceleration drive term, an experiment was defined to determine the effect of the g-seat (driven by normal acceleration only) on the simulator pilot's performance. The experiment consisted of a tracking task with the pilot's tracking reference (a standard reticle pattern) driven by a square wave. The studies were conducted in the DMS using an F-14 simulation as the test aircraft. The pilot's task required tracking a maneuver (at a constant range of 1500 ft) flown by one of the test pilots and stored on permanent files for computer playback. This provided a repeatable task for evaluation of the pilot's performance with and without the g-seat. The target maneuver consisted of a 3g wind up-turn at a constant airspeed of 325 knots. The pilot's tracking reference (reticle) was driven during each run from 10^{0} lead to 5^{0} lag and vice-versa every 10 seconds. This caused the pilot to reacquire the target every 10 seconds (Figure 12) increasing and decreasing "g" from the 3g nominal point. The reticle was equipped with

a standard range analog bar scaled for 1500 feet at the 6 o'clock tab. This provided range information to aid the pilot in maintaining a 1500 foot range to the target throughout the run. For data analysis purposes, the tracking task is broken down into four basic parts as shown in figure 12. These parts are: (1) transitioning from -10^{0} (lead) reticle setting to $+5^{0}$ (lag) reticle setting (+T), (2) tracking at $+5^{0}$ reticle setting (+S), (3) transitioning from $+5^{0}$ reticle setting to -10^{0} reticle setting (-T), and (4) tracking at -10^{0} reticle setting (-S). The pilot is considered to have transitioned when the vertical tracking error (TKE) reaches 80% of the required value (-10^{0} or $+5^{0}$). Each data run lasts approximately 70 seconds. At the beginning of a run there is a 10 second period for the pursuit craft to stabilize. The 70 second data runs alternate seat-on, seat-off conditions and the runs are grouped into sessions. One session consists of 10 sixty-second runs, five with seat-on and five with seat-off.

Statistical Performance and Analyses Measures

During each data run, eleven system states are recorded every 1/16-second. Variables recorded (raw data) are vertical tracking error (TKE), lateral tracking error (TKL), total tracking error (TKC), normal acceleration (NZ), pitch rate (THEO), roll rate (PDT), range to target (RT), reticle command (REI), stick deflection for pitch (DE), stick deflection for roll (DA), rudder deflection (DR), reticle switching time (SWT) and time (T). This raw data is then transformed to performance measures.

In order to create the performance measures, four measurement calculations are used. They are the arithmetic mean, root mean square, maximum, and minimum. These calculations are applied to the four basic parts of the reticle switch cycle and the eleven system states. Performance measures such as mean normal acceleration during a positive transition from -10^{0} to $+5^{0}$ (MNZ+T), mean normal acceleration during a negative transition from $+5^{0}$ to -10^{0} (MNZ-T) and mean normal acceleration during a positive tracking (MNZ+S) are available from the program. Also, the positive transition times (TS+) and the negative transition times (TS-) are used as performance measures. Altogether ninety performance measures were created and analyzed to determine whether the g-seat affected pilot performance.

In order to analyze the performance measures, two statistical tests were used. They were the student's t-test for paired and unpaired data and the variance ratio test. In addition to these tests, other pertinent statistical parameters computed included: mean values for seat-on and seat-off conditions, variances for seat-on and seat-off conditions, total variances, and correlation matrices.

Presentation of the Results

Two sets of pilots were used in this study. The first set contained two Langley test pilots with many hours in fighters and in simulators. These two test pilots were used to scale the g-seat and as a result were very experienced with the g-seat and the simulator. The second set contained five NASA test pilots with varying degrees of time in fighter aircraft and little famialiarity with the DMS and g-seat. The first set of pilots flew 7 sessions per pilot for data. The first two of which were not used to ensure that the pilots were far along learning curves. The second set of pilots flew 4 sessions per pilot for data. The first two of which were not used as before. None of the 5 pilots in this group had flown the task before the study began A large sample of pilots (4 or more) with about 7 sessions of the experiment would have been the ideal situation, but due to the limited number of Langley test pilots and their busy work schedule, this was not possible. Hence, two samples were used; a small sample, set one, with many sessions, and a larger sample, set two, with fewer sessions. The pilots in both sets used a wide variety of approaches to tracking the target. This variation can be seen by looking at the average transition times for each pilot shown in Table 2. Some pilots used a near maximum aircraft pitch rate to transition which resulted in large overshoots/undershoots and larger oscillations about the desired tracking, while others transitioned much slower to ensure much smaller overshoots/undershoots and better steady-state tracking. Thus, the pilot samples cover a large range of approaches to the task.

Table 3 presents a summary of the analysis for the 2-pilot set and Table 4 presents a summary of the analysis for the 5-pilot set. Contained in the table are the results of the variance ratio test for seat-on variances versus seat-off variances and the two-sided students-t test on paired data. The probabilities listed are those of the event, "the difference between seat-on and seat-off is not due to chance." One minus any of the probabilities will give an α-level at which the test result is considered significant. Only probabilities greater than or equal to .9 are listed. A computer subroutine was used to calculate the probabilities from an f-distribution and a t-distribution. Round-off and truncation error results in some probabilities being given as 1.000. The arrows beside the

probabilities indicate whether the measures tested were lower (↓) or higher (↑) for the seat-on condition. It is considered important that over 90% of the significant measures for both pilot sets combined have lower variances for the seat-on condition. This would indicate that the pilot gets information from the seat which allows more precise control of his aircraft, thereby lowering the variance of some performance measures.

The pilots were each required to fill out a questionnaire (fig. 14) concerning the realism of the seat and any effect they thought the g-seat had on their performance. The comments given by each pilot indicated that they thought that they handled the airplane more gently with the seat on. This appears to be verified by the results of statistical tests on the longitudinal measures which show lower mean values for aircraft parameters (pitch rate, normal acceleration, longitudinal stick position) and generally higher means for the longitudinal performance measures (vertical tracking error and transition time). The pilot's comments also indicated that the aircraft appeared to be "easier to control" or "better damped" in roll with the seat on. This can be seen in the data which shows a large number of significant measures in the variances and means for the lateral-directional measures; even though the task was essentially vertical tracking. The lateral problem seems to come from the pilots making lateral corrections to track the target aircraft and consequentially being "out of plane" with the target when transitioning. The seat appears to be providing (through the normal acceleration drive signal) information which makes it easier to make the lateral corrections, i.e., sensing the out of plane accelerations more rapidly. Other pilot comments indicated good to excellent realism for the normal acceleration cues. None of the pilots considered that the seat had any noticeable time lag.

Conclusions

Objective (statistical test results) and subjective (pilot comments) evaluations of the effect of the g-seat on pilot performance during a tracking task indicates that the g-seat does affect the performance of the man/machine system. The g-seat gives information that allows more precise control of the aircraft. This is shown by significant differences in the variances of many response measures for seat-on versus seat-off conditions and over 90% of the response measures that do show a significant difference have a lower variance for the seat-on condition. This is further supported by pilot comments. A surprise result was the positive effect the g-seat had on lateral control problems. Again the objective and subjective evaluations supported each other. Pilot comment said that the aircraft appeared to be easier to control or better damped in roll with the seat-on. Again, significant differences in the means and variances of lateral response measures implied that the g-seat supplied information that aided lateral control of the simulated F-14 aircraft. Analysis of the data from this experiment is continuing. Tests to determine the pilot describing functions for the seat-on and seat-off conditions are planned. The seat and back drive equations are being modified to drive the g-seat system as a function of normal acceleration, roll acceleration, directional, and longitudinal accelerations.

1. Ashworth, B. R.: A Seat Cushion to Provide Realistic Acceleration Cues for Aircraft Simulators. NASA TM X-73954, 1976.

2. Singer, S. F.: PROGRESS IN THE ASTRONAUTICAL SCIENCES. Interscience Publishers, Inc., c.1962.

3. Ashworth, B. R.; and Kahlbaum, William M., Jr.: DESCRIPTION AND PERFORMANCE OF THE LANGLEY DIFFERENTIAL MANEUVERING SIMULATOR. NASA TN D-7304, 1973.

TABLE 1. SEAT CUSHION DYNAMIC RESPONSE CHARACTERISTICS

Command	Maximum Time Lag
50% Step	65 milliseconds
Full Amplitude Sinusoidal Response	35 milliseconds Constant over (0 - 8 hz)

TABLE 2.- PILOT TRANSITION TIMES

PILOT		Average Transition Time seconds
(1A)	TS+	3.77
	TS-	4.26
(2A)	TS+	4.03
	TS-	5.09
(1B)	TS+	3.50
	TS-	3.13
(2B)	TS+	3.47
	TS-	3.61
(3B)	TS+	2.95
	TS-	2.96

TABLE 2. Concluded.

		Average Transition Time seconds		
PILOT				
(4B)	TS+		1.97	
	TS-		1.94	
(5B)	TS+		2.41	
	TS-		2.18	

TABLE 3(a). SIGNIFICANT VARIANCES FOR THE TWO-PILOT SAMPLE

↓ - Variance less seat-on
↑ - Variance more seat-on

Measures		Probability
TS+		.962 ↓
TS-		-
+T	Longitudinal	
MTK +T		.949 ↓
-T	Longitudinal	
MDE -T		.975 ↑
MTD -T		.995 ↓
MNZ-T		.976 ↓
TD MIN-T		.999 ↓
NZ MIN-T		1.000 ↑
+S	Longitudinal	
MDE +S		.955 ↓
TD MAX +S		.943 ↓
NZ MIN +S		.943 ↓
-S	Longitudinal	
TD MAX -S		.929 ↑
+T	Lateral	
MPDT +T		.926 ↑
PDT MIN +T		1.000 ↓
PDT MAX +T		1.000 ↑
-T	Lateral	
MDR -T		.995 ↑
MTKL -T		.932 ↑
MPDT -T		.991 ↓
PDT MAX -T		.968 ↑
+S	Lateral	
MDA +S		.993 ↑
MPDT +S		.996 ↓
PDT MAX +S		.993 ↓

TABLE 3(a). Continued.

↓ - Variance less seat-on
↑ - Variance more seat-on

Measures		Probability
-S	Lateral	
MDA -S		.956 ↑
PDT MIN-S		.998 ↓

TABLE 3(b). SIGNIFICANT MEANS FOR THE TWO-PILOT SAMPLE

↓ - Mean less seat-on
↑ - Mean more seat-on

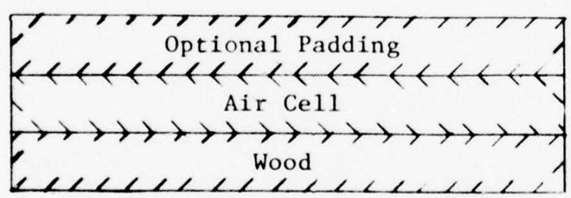
Measures		Probability
TS+		-
TS-		.972 ↓
-T	Longitudinal	
MDE -T		.998 ↑
MTD -T		.958 ↑
TD MAX -T		.918 ↑
-S	Longitudinal	
MTK -S		.970 ↑
NZ MAX -S		.993 ↑
TD MIN -S		.991 ↓
NZ MIN -S		.997 ↓
+T	Lateral	
PDT MIN +T		.980 ↑
PDT MAX +T		.987 ↑
-T	Lateral	
MDR -T		.958 ↑
+S	Lateral	
PDT MAX +S		.992 ↑
-S	Lateral	
MTKL -S		.985 ↑
PDT MAX -S		.965 ↑

TABLE 4(a). SIGNIFICANT VARIANCES FOR THE 5-PILOT SAMPLE

5 PILOTS MIXED		↓ - Variance less seat-on ↑ - Variance more seat-on
Measures		Probability
TS+		-
TS-		.918 ↓
+T	Longitudinal	
MTK +T		.921 ↓
+S	Longitudinal	
MDE +S		.971 ↓
-S	Longitudinal	
MTK -S		.972 ↑
+T	Lateral	
MDA +T		.971 ↓
PDT MAX +T		.929 ↓
-T	Lateral	
MDA -T		.960 ↓
PDT MIN -T		.965 ↑
+S	Lateral	
PDT MIN +S		.987 ↓
-S	Lateral	
MTKL -S		.993 ↑
PDT MAX -S		.968 ↓
PDT MIN -S		.967 ↓

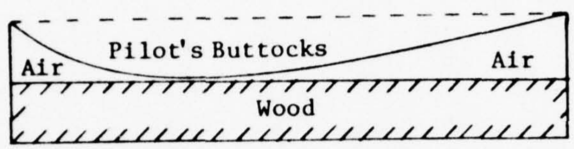
TABLE 4(b). SIGNIFICANT MEANS FOR THE 5-PILOT SAMPLE

5 PILOTS MIXED		↓ - Mean less seat-on ↑ - Mean more seat-on
Measures		Means 0-60 sec Prob.
-T	Longitudinal	
TD MAX -T		.973 ↑
+T	L Lateral	
MDR +T		.930 ↑
-T	Lateral	
MDA -T		.963 ↓
-S	Lateral	
MDR -S		.930 ↑
MPDT -S		.970 ↑

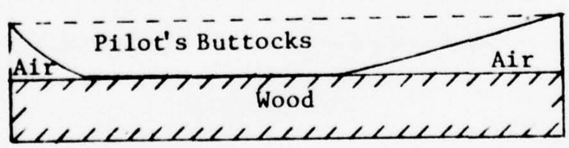


Cross Section

Figure 1. Basic Seat Concept for One Cell



(a) Neutral - 1g Bias



(b) Positive g

Figure 2. Seat Operation

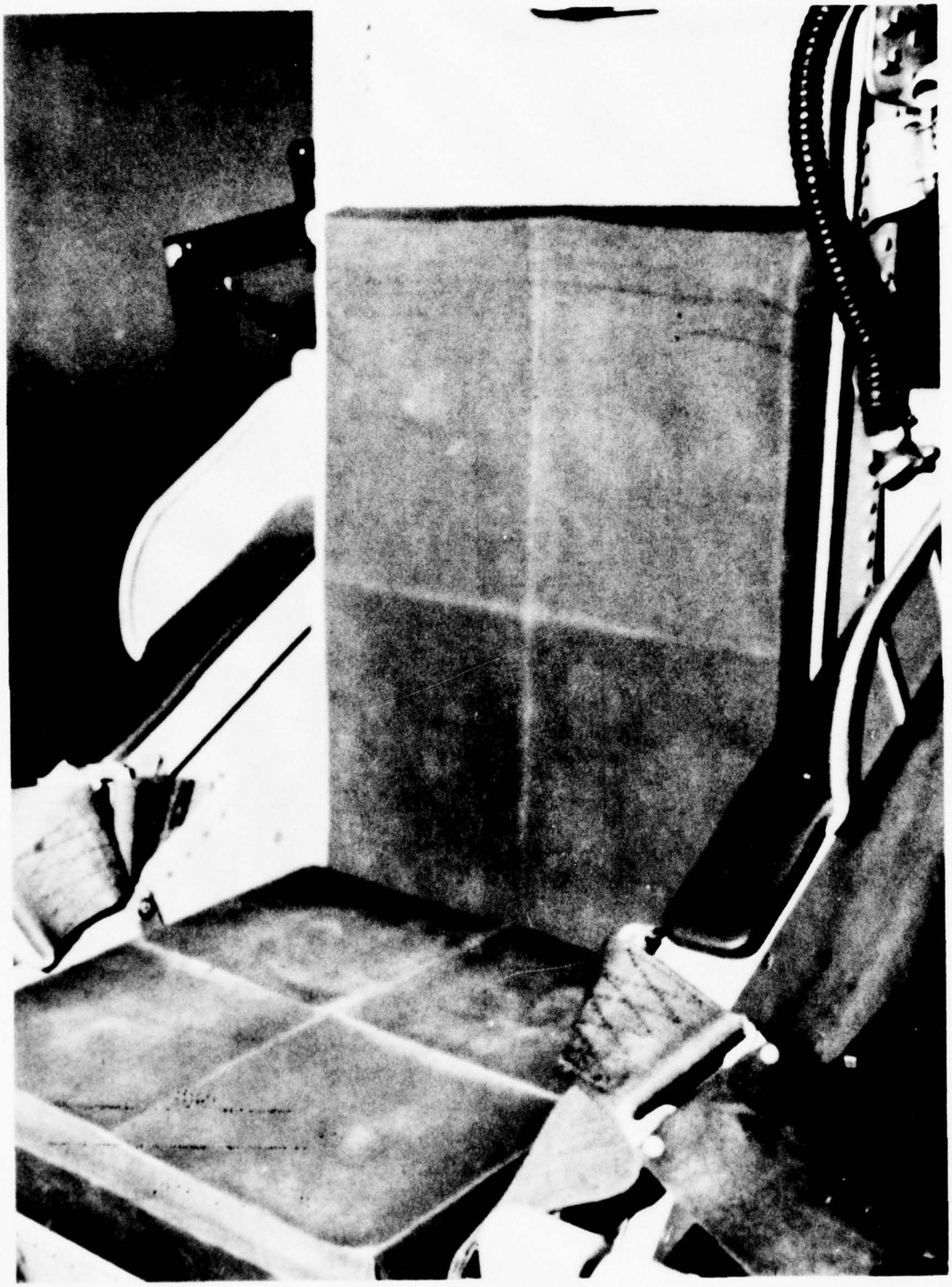


Figure 3. Seat and Back Cushions
(Four Cells Each)

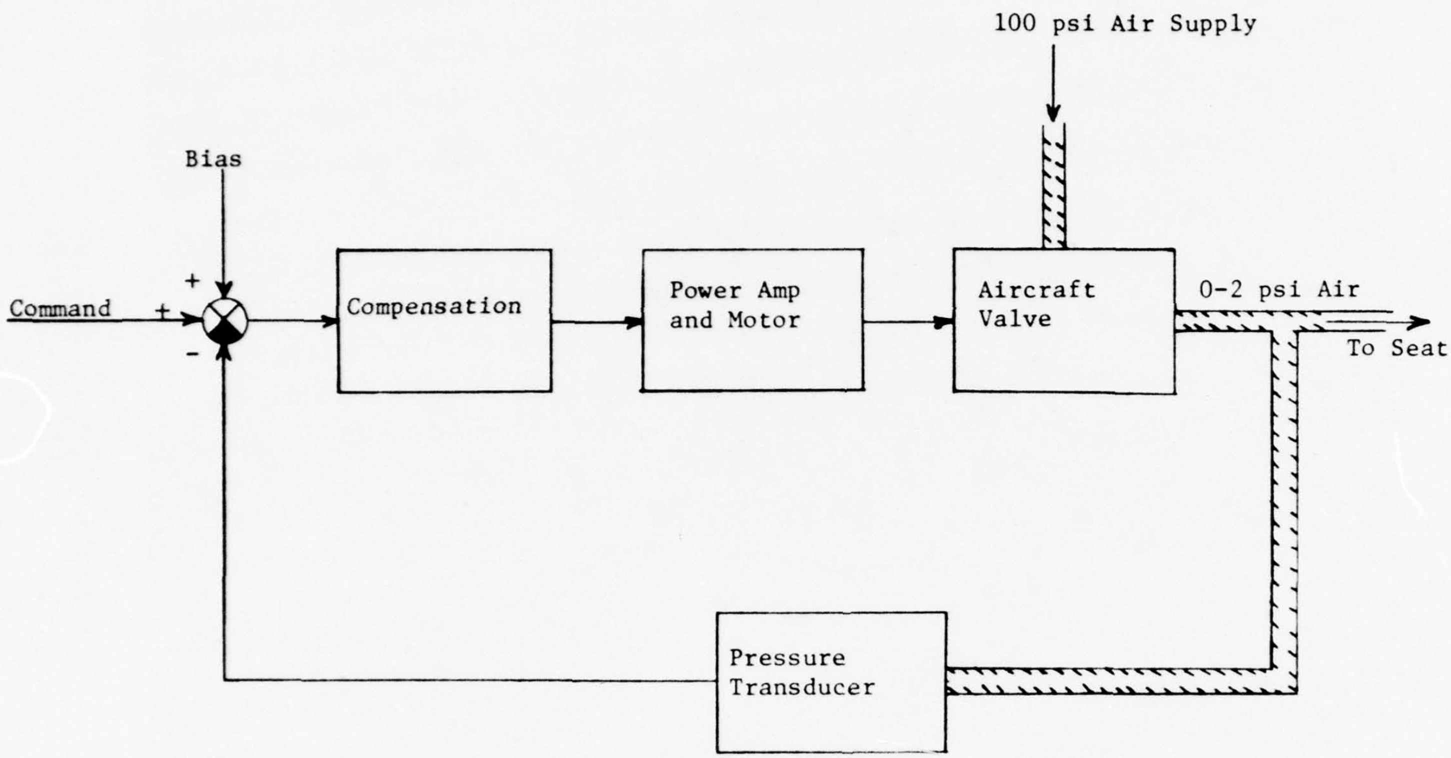


Figure 4. Servo Controller for One Seat Compartment

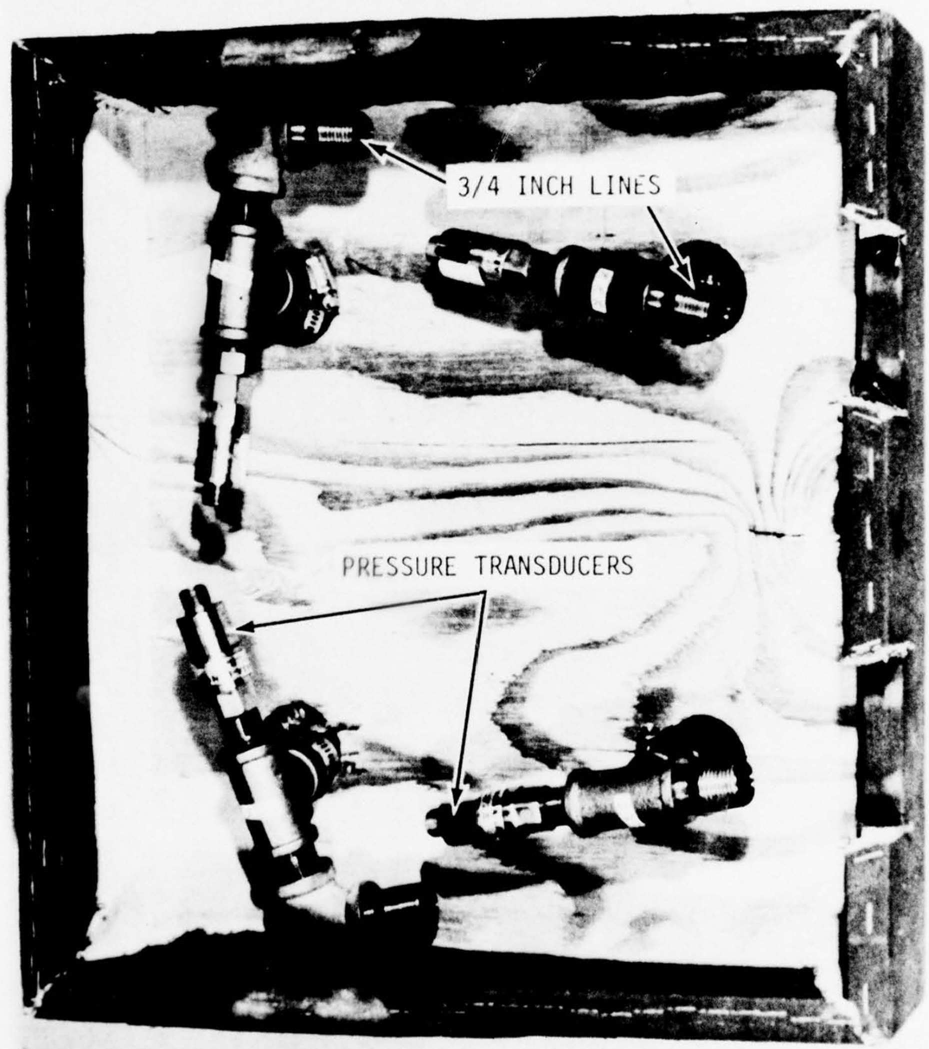


Figure 5. Seat Cushion Bottom View

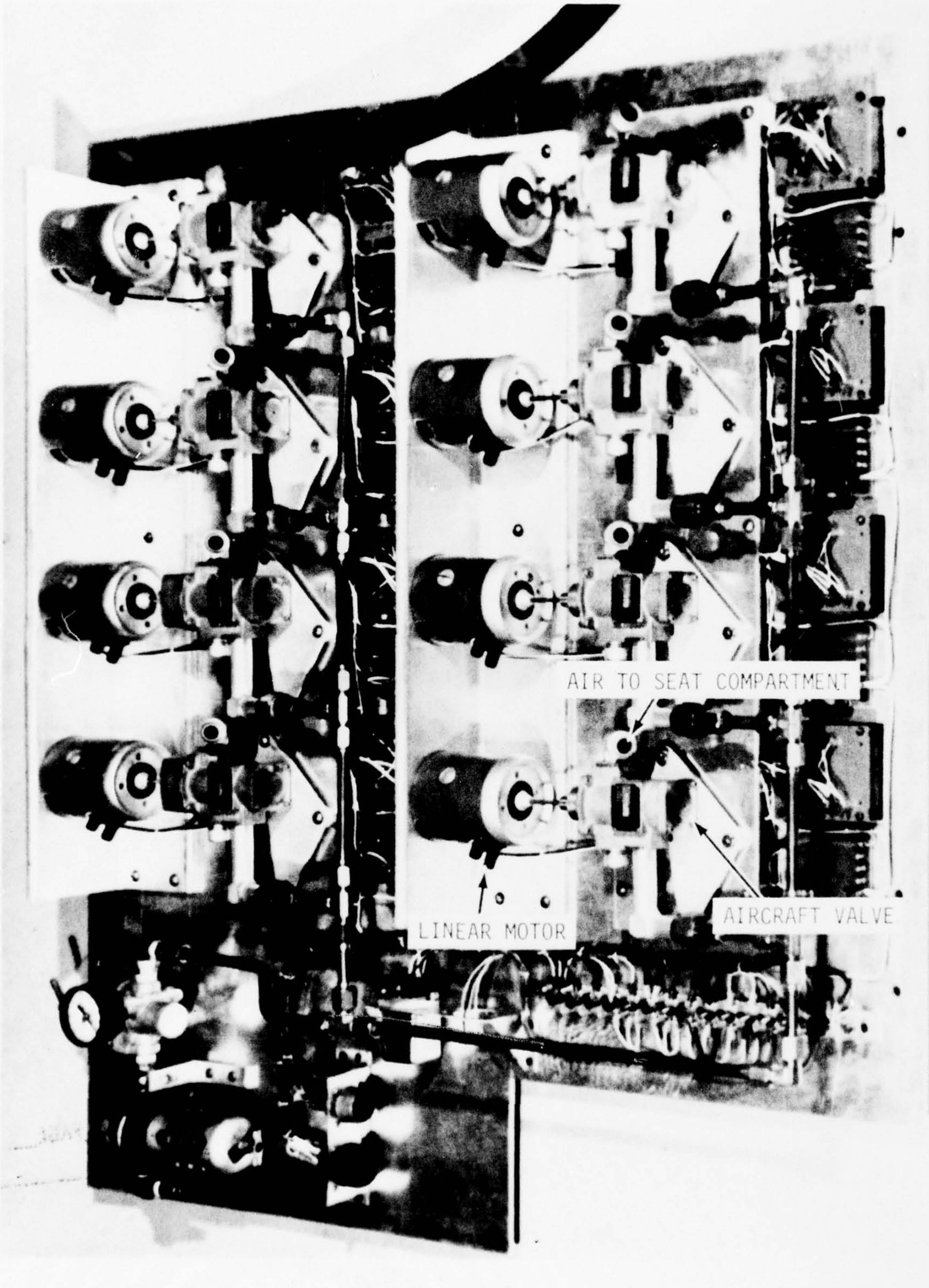


Figure 6. G-Seat Pressure Controllers

Figure 7 a.- Negative g Response

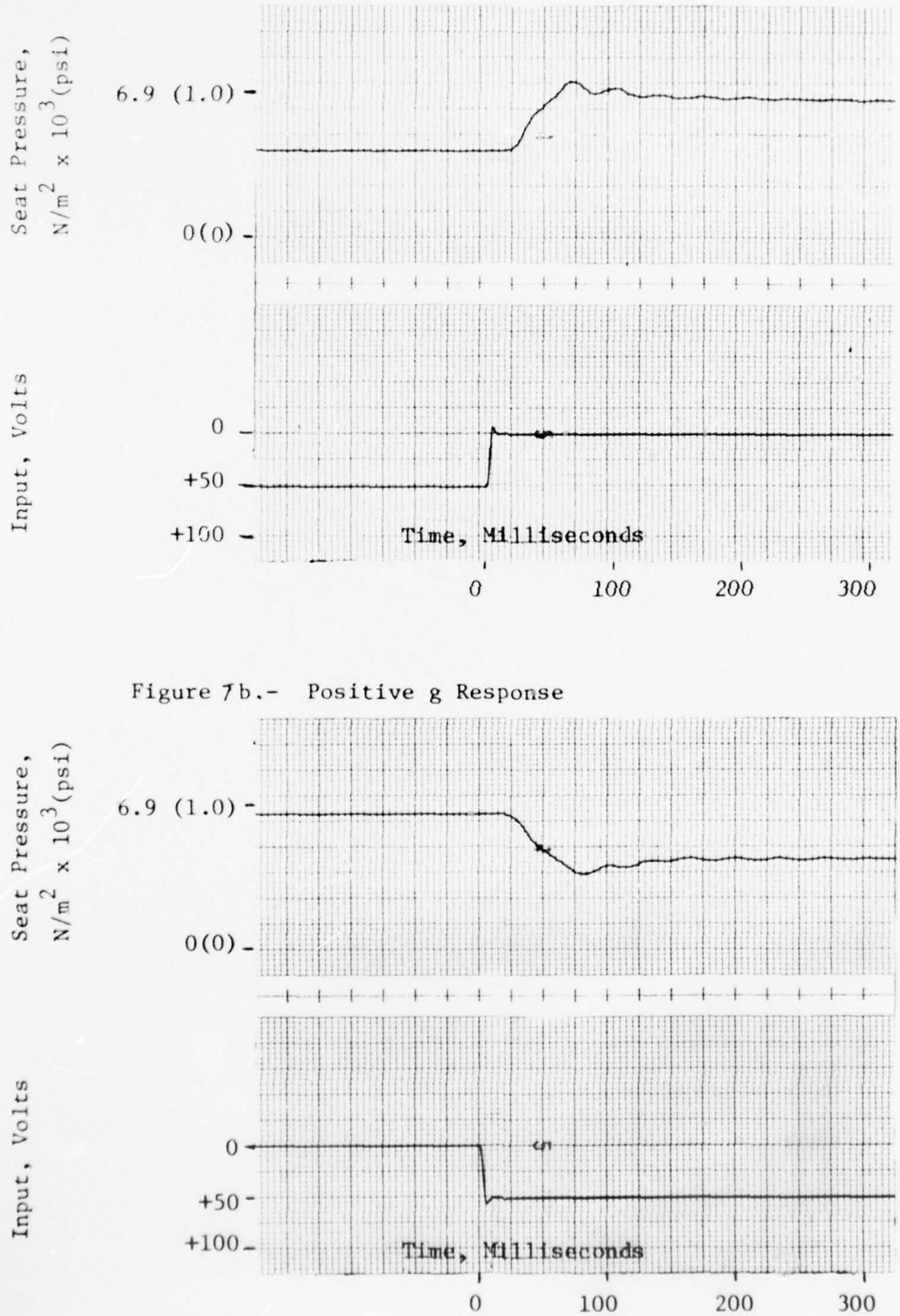


Figure 7. G-Seat Step Response for 50% Step Input (1 cell)

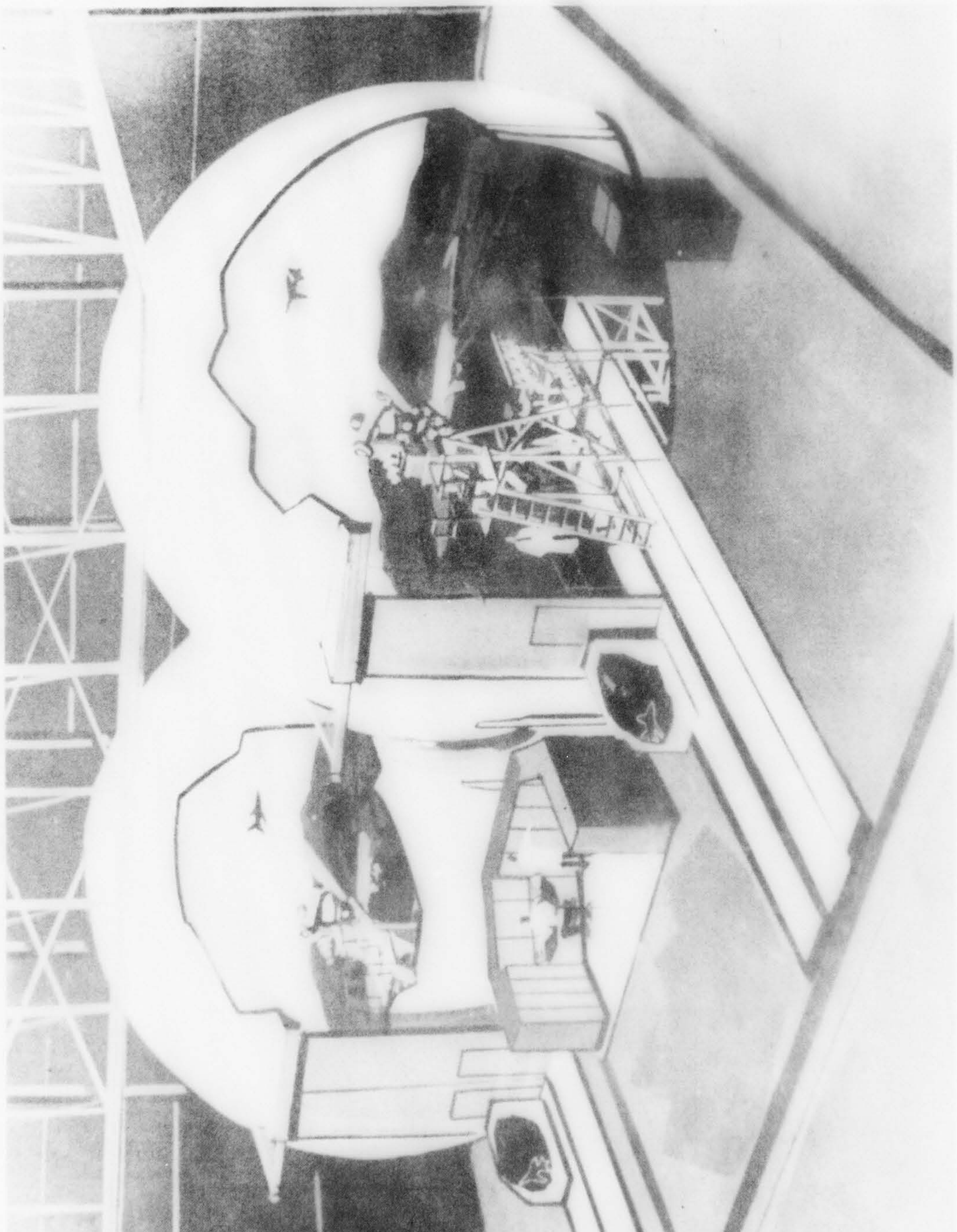
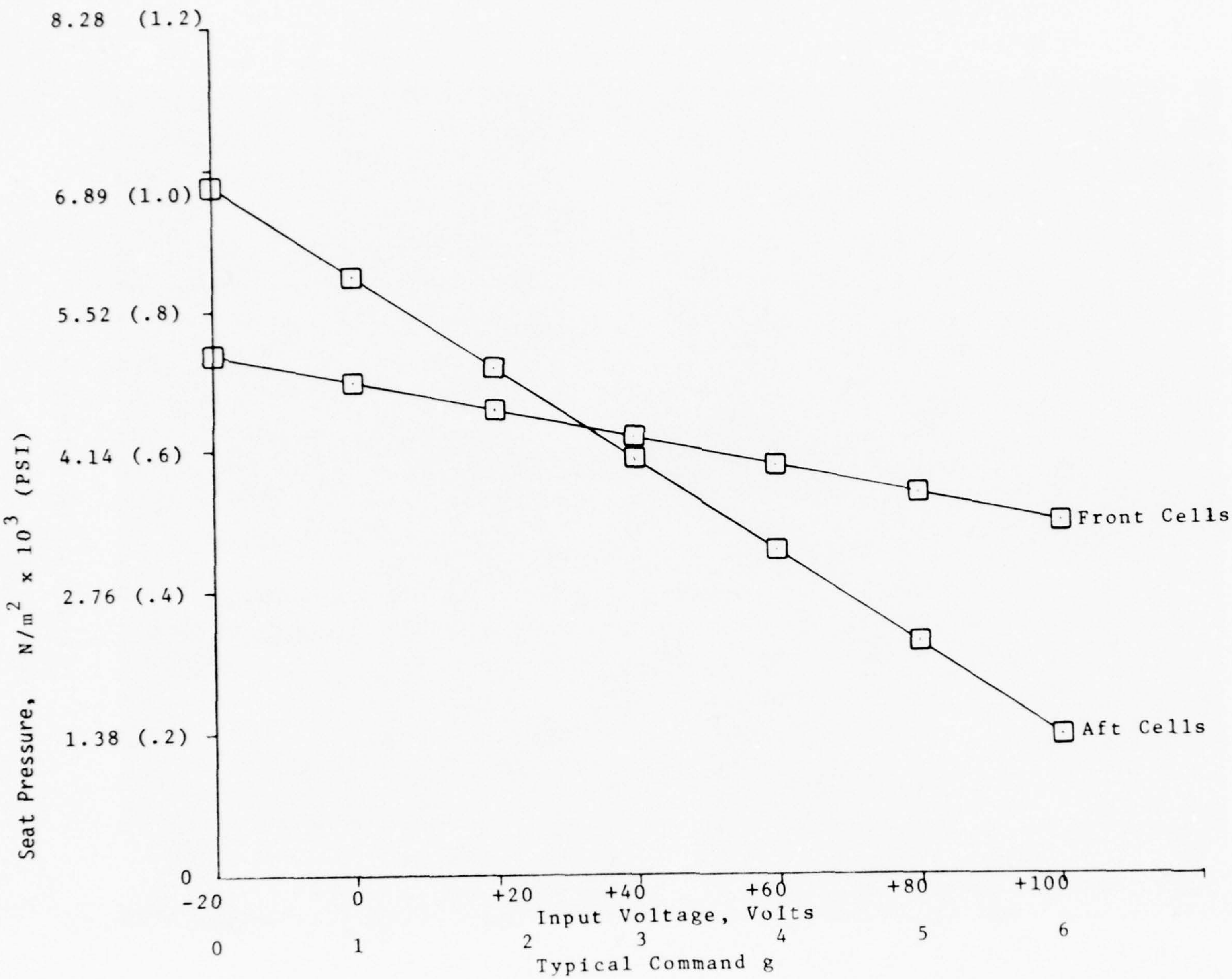


Figure 8. DMS Facility

Figure 9. DMS Pilot's View



Scaling for 160-Pound Pilot

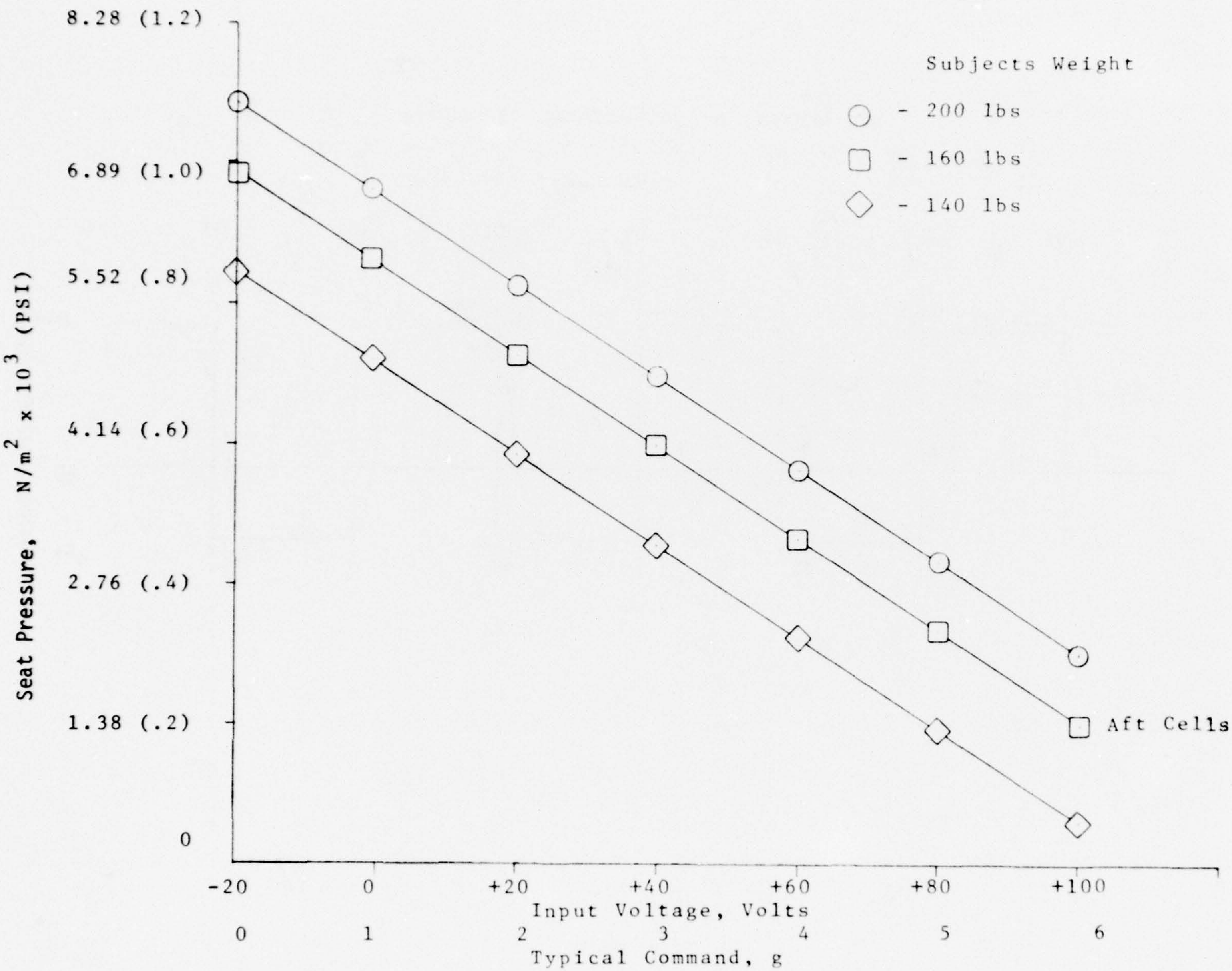


Figure 11. G-Seat Scaling as a Function of Pilot Weight

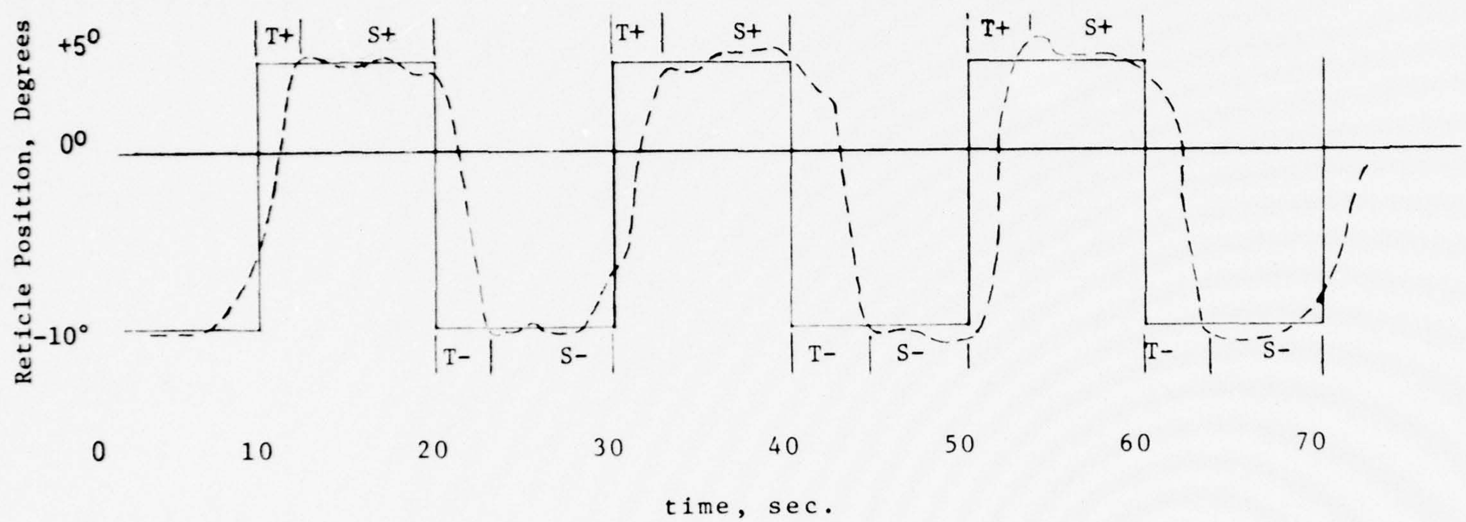


Figure 12. Structure of One Computer Run

Please note the realism of the seat on the scale below:

	Excellent	Good	Fair	Poor	Unacceptable
Realism - Overall					
Positive G					
Increasing +G					
Decreasing +G					
Negative G					
Increasing -G					
Decreasing -G					

Does the presence of the seat have any effect on your:

1) Overall Tracking performance? YES ____ NO ____
   a. over shoot YES ____ NO ____
   b. time to stabilize YES ____ NO ____

2) Control inputs? YES ____ NO ____

3) Maximum A/C rates? YES ____ NO ____

Is there any noticeable time lag in the seat response to your inputs?

YES ____ NO ____

Additional Comments:

Figure 13. Pilot Questionnaire

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SIMULATOR TRAINING AND PLATFORM MOTION IN AIR-TO-SURFACE WEAPON DELIVERY TRAINING

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SUMMARY

The objectives of this research were to determine: (1) the extent to which generalized, conventional, air-to-surface (A/S) weapons delivery training in the Advanced Simulator for Pilot Training (ASPT) transferred to a specific aircraft; (2) the contribution of six degree of freedom platform motion to the transfer of training from simulator to aircraft; and (3) the differential effects, if any, of this simulator training on student pilots of different ability levels. These objectives were accomplished by selecting 24 students in the lead-in A/S training course at Holloman AFB to serve as subjects. These subjects progressed through lead-in training, receiving all training except the A/S flights, and then proceeded to Williams AFB where they were assigned into matched experimental and control groups. At Williams AFB, all of the subjects received academic training in weapons delivery techniques and procedural training on F-5B operations. At this point, the students in the control group flew two data collection sorties in the F-5B aircraft, performing 10°, 15°, and 30°, bomb deliveries. The experimental groups received A/S weapons delivery training in ASPT on 10°, 15°, and 30° bomb deliveries with a fixed number of trials on each event. The experimental subjects then received two data collection flights in the F-5B identical to those received by the control group. Analysis of the results proved that simulator training significantly increased air-to-surface weapons delivery skills (e.g., approximately double the number of qualifying bombs, a one-fourth reduction in circular error) but that platform motion was not a contributing factor in this process. It was also found that novice student pilots of greater initial ability benefit most from such simulator training when a minimum fixed number of trials is used.

BACKGROUND

The air-to-surface mission is a major role for the Tactical Air Command (TAC). A specialized aircraft is being procured to support this operational requirement for which the Air Force plans extensive simulator procurements in order to reduce training costs while maintaining operational readiness. In light of this fact, it is highly desirable to determine the effectiveness of candidate simulator configurations prior to their acquisition by the user. From the user's viewpoint, there are two aspects to this process. First, the simulation must provide the cues essential for training; and second, there must be positive training transfer from the simulator to the aircraft. From a budgetary standpoint, these two requirements are valid, but the cost element must be considered as well. Unnecessary features should not be purchased: the simulation must not only be effective, but also it must be efficient.

One expensive flight simulator feature, of which the universal essentiality is not certain, is platform motion. The question as to whether the existence of simulator platform motion enhances the training effectiveness of the device is an issue of considerable importance. Using a moving platform to provide vestibular and kinesthetic cues to the pilot is a costly process. Not only are initial expenses increased, but life cycle costs are also inflated. Unless some positive training value can be demonstrated for the presence of motion, cost-avoidance consideration must force its exclusion from the simulator.

The Air Force Human Resources Laboratory (AFHRL) recently participated in a study (ASD Project 2235) which facilitated the development of a visual scene capability on the ASPT that included a conventional air-to-surface weapons delivery complex and the display of tactical targets for more advanced operational training. This visual capability, when combined with objective scoring strategies and the existing motion system permitted the investigation of the transfer of training phenomena described in the present study.

Air-to-surface weapons delivery is a high-risk area of training for newly rated pilots. Large Air Force expenditures for simulation of this activity are imminent. Therefore, a determination of both the feasibility of simulator training in this area and an assessment of the contribution of platform motion to simulator effectiveness in this context was deemed essential.

Literature Review. There have been numerous studies investigating the effects of platform motion upon piloting tasks. Many of these have been directed towards determining the degrees of freedom required for motion systems in particular settings as well as what levels of fidelity are needed (Bergeron, 1970; Jacobs, Williges, Roscoe, 1973). This body of research, however, is equivocal, and

findings have not always been consistent from study to study.

Certain studies have shown that motion produces improved pilot performance in controlling the simulator (Borlace, 1977, Brown, Johnson and Mungall, 1960). In this vein, Rathert, Creer, and Sadoff (1961) demonstrated that varying the fidelity of motion cueing directly affected the pilot's performance in the simulator. Koonce (1974) investigated the training effectiveness of platform motion using three conditions of motion cueing (i.e., no motion, sustained motion cueing, and washout motion cueing). This study reported an increase in pilot performance in the simulator when either condition of motion cueing was present.

From Koonce's study, it is seen that the evidence supporting the posi ive effects of high fidelity motion cueing is not firmly established. Demaree, Norman, and Matheny (1965) concluded that in many instances the level of fidelity could be reduced without any appreciable performance decrement on tracking tasks. Huddleston (1966) reported that motion may not be necessary for those piloting tasks performed in the more stable flight regimes, although it may be beneficial in highly dynamic regimes. Finally, a follow-on study to Koonce (Jacobs and Roscoe, 1975) may have revealed a critical facet of the issue. It was found that pilot performance, in terms of errors committed, improved in the simulator with the presence of either normal washout motion or random washout motion where the latter condition provided appropriate onset cueing, but random directional cueing. Perhaps motion serves only to alert the pilot to a change in system conditions and rarely has any intrinsic stimulus value beyond this point (Irish, Grunzke, Gray, and Waters, 1976). Simple "movement," not complexly driven motion platforms, may provide sufficient cues for simulation.

A plethora of studies attest to the training value of simulation (Woodruff and Smith, 1974; Reid and Cyrus, 1974; Caro, 1970; and Prophet, Caro and Hall, 1972). But the effectiveness of simulator training varies enormously when viewed across specific applications, and it is wise to pretest whenever possible. In addition, individual differences in the student population may produce widely different effects of such training. The present study was designed to investigate these possibilities.

Problem Statement. At the present time, TAC air-to-surface training is taught in tactical aircraft. An alternative, if demonstrated to be effective, is the use of flight simulators designed with air-to-surface capabilities. A related issue is the efficiency of this training for student pilots of different ability levels. If the payoff of simulator platform motion does not increase the training transfer to the aircraft, significant reductions in the life cycle costs of the device could be realized.

Objectives. The objectives of this research were to determine: (1) the extent to which generalized, conventional, air-to-surface weapons delivery training in the ASPT transfers to a specific aircraft; (2) the contribution of six degree of freedom platform motion to the transfer of training from simulator to aircraft; and (3) the differential effects, if any, of this simulator training on student pilots of different ability levels.

METHOD AND PROCEDURES

The main theme followed throughout the study was that the approach should be intensely realistic in terms of Air Force operations. This was the determining factor in the study's methodology. Accordingly, it was decided to select a homogeneous group of inexperienced pilots who had already been identified for fighter training, train them on specified tasks in the simulator, then measure their performance on the same tasks in an aircraft on an actual gunnery range. The result was a simple study, easily and quickly understood, that produced information directly applicable to Air Force areas of concern.

Subjects. The personnel who serve as subjects in simulation research are usually found to be the major single source of variance when the analysis of the experimental results is completed. In this study, great care was taken to remove as much of this unwanted variance as possible through the use of judicious selection techniques and counterbalancing.

Subject Background and Selection. It was decided that the most representative source of subjects would be recent Undergraduate Pilot Training (UPT) graduates who had been identified for fighter assignments. These novice pilots receive a short six-week fighter lead-in training course at Holloman Air Force Base, New Mexico, after graduation from UPT and prior to arrival at their Replacement Training Unit. The lead-in course is designed to improve formation flying skills and to provide an introduction to high performance maneuvering and to air-to-ground weapons delivery. At the time of this study, the course contained 19 sorties in the two-place T-38 aircraft, the same aircraft flown in UPT.

The subjects were given the entire lead-in training course with the exception of the air-to-surface indoctrination. This required

deleting two T-38 sorties which were replaced by two sorties in the F-5B at Williams Air Force Base as part of the study. The two sorties deleted at Holloman Air Force Base are flown "dry" since the T-38 does not have the capability to deliver ordnance, whereas the two F-5B sorties gave the subjects the opportunity to drop twelve BDU-33 practice bombs which would serve as criterion measures. The subjects were randomly selected from those meeting certain administrative criteria in the training squadron at Holloman. The training squadron then developed a rank ordering of these subjects. This rank ordering was made on the basis of the student's performance during lead-in training.

Subject Assignment. Upon the completion of lead-in training, the student pilots were sent to Williams in groups of six. It was necessary to use four lead-in training classes in order to produce a total N of 24 students, eight subjects assigned to each of three groups.

The rankings given by the squadron at Holloman formed the basis for assigning each subject into either a control group which received no simulator training, or one of two experimental groups (i.e., motion and no-motion groups). For the first class, the subjects ranked 1 and 6 were placed in the motion group, 2 and 5 in the no-motion group, and 3 and 4 in the control group. Class two grouped students 2 and 5 into the motion condition, 3 and 4 into the no-motion condition and 1 and 6 were used as controls. Class three used the last available combination and class four used the first combination over again. Fortunately, this counterbalancing on student performance also produced groups that were well equated from the standpoint of mean fixed-wing flying time. The control group averaged 259 hours, the motion experimental group averaged 276 hours, and the no-motion experimental group averaged 248 hours. These minor differences were not statistically significant at the five percent level of confidence.

It is believed that this procedure accomplished its purposes: namely; subject groups matched as to ability, and a study that would allow valid generalizations on the benefits of air-to-surface simulator training to the appropriate Air Force population.

Instructor Pilots. With one exception, the study's Instructor Pilots were drawn from the 425th Tactical Fighter Training Squadron stationed at Williams. All Instructor Pilots were highly experienced in air-to-surface weapons delivery and were thoroughly briefed on the purposes of the study and their jobs within it. Special training on the ASPT console operation and advanced training features capabilities was given to the Instructor Pilots who administered the simulator training.

Apparatus. The apparatus used in the study consisted of two devices: the Advanced Simulator for Pilot Training (ASPT) and, the F-5B aircraft.

ASPT. The Advanced Simulator for Pilot Training located at the Air Force Human Resources Laboratory/Flying Training Division (AFHRL/FT) was used for the training portion of the study. Technical references for this device are found in Hagin and Smith, 1974; and Rust, 1975, but a short description follows.

ASPT has two fully instrumented T-37 cockpits mounted upon six-degree-of-freedom motion platforms. The synergistic motion system has six active drive legs with approximately five feet of vertical travel and four feet of horizontal travel. Displacement capabilities include: pitch -20 degrees to +30 degrees; roll ±22 degrees; and yaw ±32 degrees. These displacements are intended to provide initial (onset) cues for all maneuvers. The 31-bellow pneumatic G-seat is designed to provide more continuous cues than the motion platform and accomplishes this by the orderly inflation and deflation of the bellows in response to the requirements of each particular maneuver.

The ASPT visual system is comprised of seven 36-inch monochromatic cathode ray tubes placed around the cockpit giving the pilot +110 degrees to -40 degrees vertical cueing and ±150 degrees of horizontal cueing. The computer generated visual scene has the capability to display information for most pertinent ground references (mountains, runways, hangars, etc.) within a 100 square nautical mile area of Williams AFB. The configuration for this study included the conventional gunnery range visual data base developed for Project 2235 and the depressable bombing sight (A-37 Optical Sight Unit) installed for that project (Hutton, et al., 1976).

The aerodynamic math models driving the simulator were those of the T-37 aircraft. The feasibility of changing these models to increase the performance of the simulator to more representative airspeeds and handling qualitites of fighter type aircraft was investigated. Estimates of that effort placed unacceptable time delays on the project which would have not allowed information to be provided to the using command within the required time frame.

A major decision made in establishing the simulator configuration dealt with the G-Seat. The G-Seat can serve as a platform motion surrogate by providing vestibular and kinesthetic cues. If the G-Seat had been included as an

independent variable, two additional groups of subjects would have been required for the experiment. This action would have increased the size and duration of the effort by two-thirds. Due to the urgent demand for immediate information on platform motion effects, a larger study was not a viable option. Consequently, it was decided that the G-Seat would be a fixed study factor.

The fully operative motion condition was chosen for the G-Seat configuration. The reason for this selection was that, unlike motion platforms, the inclusion of a G-Seat adds very little to either the acquisition or life cycle costs of a flight simulator. Since it seemed highly probable that all future sophisticated flight simulators would be procured with G-Seats, it was believed that the study results would have greater validity if the G-Seat were operative during the simulator training phase.

F-5B. The aircraft selected for the criterion flights was the F-5B, primarily because F-5B training is accomplished at Williams Air Force Base and the proximity of instructor pilots and aircraft greatly simplified this portion of the data collection. An additional reason for its selection was because it is a two-seat aircraft and two data collection flights per subject could be scheduled with very little checkout time in the aircraft, since an instructor would be on board to perform all tasks not required as part of the study (as well as providing adequate flight safety).

In all, the F-5B proved to be an excellent choice as the criterion test vehicle for measuring the ability of the subjects to perform air-to-surface weapons delivery. The flight characteristics of the F-5B are similar to those of the T-38 aircraft which the subjects had flown for approximately 110 hours in UPT and another 20 hours during lead-in training. Differences in operational procedures and "switchology" were prebriefed prior to each aircraft mission and presented no problems during the data collection flights.

Independent Variables. Four independent variables were used in the study. The first of these, training conditions, represents the weapons delivery training received by the subjects at Williams AFB. There were three levels of this variable: no simulator training (Control Group); simulator training with platform motion (Experimental Group 1); and, simulator training without platform motion (Experimental Group 2). The specific syllabus content and student flow for all three conditions will be covered in a subsequent section.

The second independent variable, coincident with the first, was simulator platform motion. There were two levels of this variable: level one used the full six degree of freedom platform motion available; for level two the platform was stationary.

The third independent variable consisted of the weapons delivery tasks performed by the study subjects. Three different weapons delivery tasks were selected: the high-drag 10 degree dive angle; the high-drag 15 degree dive angle; and, the 30 degree angle dive bomb.

The final independent variable, initial flying ability, was chosen to give greater experimental control and to permit group comparisons on the effects of simulator training as a function of student ability. As stated above, the subjects were rank ordered by the training squadron at Holloman on the flying ability they demonstrated during lead-in training. This served two purposes: first, it allowed counterbalancing of subjects so that there were matched groups in the three training conditions; second, it made possible comparisons on the value of simulator training between students judged to have greater, as contrasted to lesser, initial flying ability.

Study Design. The design used throughout the study was an elementary two-factor "mixed" analysis of variance classified by Lindquist (1953) as a Type I design. The basic design lent itself nicely to the analysis requirements because for two-level contrasts (i.e., motion versus no-motion, superior versus inferior students), it conveniently collapses in simpler paradigms. The three weapons delivery tasks (i.e., 10 degree, 15 degree, and 30 degree dive angles) comprised one factor of this design, while group associated independent variables (i.e., conditions of training, simulator motion configurations, and initial flying ability) constituted the other.

The design was used for the many univariate analyses of variance performed on the data as well as the two multivariate cases.

Dependent Variables. There were two sets of dependent variables used in this study, and both sets had two types of measurements within them.

Aircraft Performance Dependent Variables. Two classes of dependent measures resulted directly from student performance data obtained during the F-5B criterion flights. The first of these, bomb delivery accuracy, were scores from practice bombs dropped on the conventional gunnery range at Gila Bend, Arizona. The second dependent variable based on flying performance was Instructor Pilot ratings. Instructor Pilots flying with the students in the aircraft gave subjective ratings on a scale of zero to four on each bomb

delivery attempt which were converted into standard scores (mean of 50, standard deviation of 10) for analytic purposes. These ratings covered overall flying performance in the bombing pattern but excluded any consideration of the actual bomb score.

Simulator Performance Dependent Variables. Similar to the above, there were two classes of dependent measures that resulted from student performance in the ASPT. The first of these, bomb delivery circular error, is a measure comparable in every respect to the corresponding measure observed during the checkrides. A scoring algorithm in the simulator computer captured all release parameters on each delivery and computed an impact distance from the target center.

Capabilities of the ASPT were also used to record simulated flight parameters at the moment of bomb release. Airspeed, altitude, g-load, heading and dive angle were printed out for each weapons delivery. These were the parameters utilized in the multivariate analyses of variance.

Syllabus Development. The first step in the syllabus development was to determine the tasks to be flown. Consideration of F-5B and ASPT capabilities and project objectives resulted in the selection of two low-angle bombing events and one high-angle event. The two low-angle events were 10 and 15 degree simulated high-drag deliveries. The high-angle event selected was the 30 degree dive bomb. The skills required for this event are somewhat different than for the low-angle deliveries because more reliance on in-cockpit instruments is necessary to meet required release parameters.

A prototype syllabus was established and several experienced pilots with no previous air-to-surface training were selected to conduct a pretest of the mission scenarios. These trial runs provided insight into the amount of time required to conduct the training, the optimum length of each sortie, and at the same time provided experience in console operations for the instructors who would be doing the actual training. After several minor changes were made to the syllabus, the course of instruction was administered to a new UPT graduate with flying experience similar to the actual subjects. No problems were encountered and the sequence and instructional techniques were finalized prior to arrival of the first class of subjects.

Subject Training. After their arrival at Williams AFB, all of the subjects were given two blocks of "ground school" training. The first block was presented on the first morning and consisted of an introductory briefing, an overview of the study, and a short phase review of air-to-surface weapons delivery.

At this point, the control group was separated from the experimental groups and given their second block of training, an orientation to the F-5B. This block of training consisted of instruction on aircraft procedures and ended with a test on critical action emergency procedures which were required knowledge prior to flight. For these subjects, the remainder of the first day was spent on the flight line with time in the cockpit to familiarize them with armament procedures and switchology. These control subjects then flew their two data flights in the F-5B on the second and third days (one flight per day). The content of the flights will be described in the section on Testing Procedures.

After receiving the first block of ground school with the control group, the experimental groups then proceeded with their simulator training. They did not receive the second block on F-5B procedures until after the simulator training had been completed.

The syllabus for this training was divided into eight, one-hour sorties. A building block approach was followed throughout. On the first simulator mission, a short familiarization flight was provided prior to starting the actual weapons delivery training. During this time, the subjects experienced the control forces and trim changes that would occur over the airspeed ranges that were later flown. Characteristics of the simulator visual system were explained so the subjects were well-adapted to the outside cockpit environment.

After the familiarization period, the simulator was initialized to the gunnery range for the start of the air-to-surface training. The events were taught in sequence starting with the 10 degree dive angle task. The delivery was introduced with a prerecorded demonstration of the base leg and final approach portions of the pattern. The student was then reset to the same starting point and allowed to practice what he had seen. This part-task approach was selected to take advantage of the available advanced training features such as problem freeze, initialization/reset, and record/playback. After several trials, the student again viewed the prerecorded demonstration. This presentation was dynamic for all flight instruments, stick, rudder, and throttles as well as the visual scene. The Student then flew the part-task pattern again with his own performance recorded. When this was replayed, he had instant feedback which he could use to analyze his own errors. The Instructor Pilots used the problem feature frequently to stop the sequence and to point out what the student should have been seeing and doing. Finally, the full pattern was demonstrated and taught

in much the same manner as the part-task pattern.

The second and third missions introduced the 15 and 30 degree tasks using the same procedures. Reinforcement of previously learned patterns was accomplished at several points in the missions. The Instructor Pilots used mission guides in order to follow the sequence exactly on each sortie. Thus, each student in the experimental groups received the same number of repetitions on each of the three bomb delivery tasks.

Testing Procedures. Criterion performance tests were administered in the F-5B aircraft for all groups and in the ASPT for the two experimental groups.

F-5B Tests. Each subject flew flights in the F-5B. The test profile was identical for both flights and consisted of a total of nine bombing patterns on each flight. The F-5B carries six practice bombs, so with three tasks, this resulted in the delivery of two bombs per task per sortie. One extra pattern was flown on each task so a practice run could be accomplished prior to the two actual weapons deliveries.

Simulator Tests. The last two sorties in the simulator were designed to give the subject the same profiles on the simulated range that he would fly on his two aircraft sorties. Each delivery was graded using the same weapons delivery criterion measure used on the aircraft data flights and instruction was minimal. For the scored portions of these flights, the winds were set to represent conditions typical of the Gila Bend Range.

Scoring Procedures. Although the same general approach was used, real-world occurrences naturally beyond experimental control made it necessary to use slightly different scoring procedures for the aircraft criterion missions.

F-5B Tests. Ordnance dropped on the Gila Bend Gunnery Range was scored by observers positioned in towers near the bombing target. Upon impact, a small powder charge in each practice bomb discharged a puff of white smoke which was easily visible. Observers in the two towers used sighting transits to triangulate the location of the bomb impact. The triangulation readings were used to compute the distance of the impact from the center of the target. These circular error scores were relayed via radio to the aircraft after each event. Maximum distance for determining circular error was 300 feet, with anything outside this limit being reported as unscorable. These bombs were arbitrarily assigned a score of 301 feet for purposes of analysis.

Occasionally a malfunction prevented a bomb from releasing from the aircraft. These "no release" passes were rated by the Instructor Pilots since the pattern was flown but simply no bomb score was recorded. This was reflected in the analysis with some subjects having fewer total opportunities which were adjusted for mathematically. Of the total of eight malfunctions that occurred, there were seven in the Control Group, and one in the Motion Experimental Group.

Simulator Tests. The simulator had a theoretically unlimited number of bombs. Each time the pilot released a simulated bomb, the instructor received a graphical display of the bomb impact on a cathode-ray tube which depicted the target circle. He also received a printout of the exact parameters so he could analyze and critique the subjects' performance. Since the computer was scoring the bombs, there were none recorded "unscorable." No release malfunctions occurred during the simulator training.

RESULTS

The research performed in this study addressed three objectives which may be simplified into the following questions:

1. Does simulator training improve air-to-surface weapons delivery skills in novice pilots?

2. Does simulator platform motion contribute to any degree to such training?

3. Does a fixed amount of simulator training affect novice pilots of higher versus lower ability levels to the same extent?

The hypotheses tested in the analyses of results were taken directly from these questions. Accordingly, this section is organized to answer these questions in the order in which they appear.

Simulator Training Effects. The analysis of the ASPT training effects was based on a series of contrasts between the Control Group (C) and the Experimental Groups (E_1 and E_2). The data collected made possible four comparisons. The dependent variables used for these comparisons were: number of gunnery range qualifying bombs; number of gunnery range scorable bombs; gunnery range bomb circular error; and, Instructor Pilot ratings on F-5B flying performance.

Number of Qualifying Bombs. A Chi-Square was performed to test for significant differences in the number of qualifying bomb deliveries made by the C and E groups. Using TAC criteria, qualification was defined as a circular error of 105 feet, or less, for 10 degree and 15 degree dive angles and 140 feet, or

less, for the 30 degree dive angle. Both E groups were found to be significantly better than the C group at the five percent level of confidence (χ^2 =6.99). Table 1 lists the observed values and percentages for the three groups.

TABLE 1.

NUMBER OF QUALIFYING BOMBS
(Training Effects Analysis)

	Qualifying Number	Qualifying Percentage	Misses Number	Misses Percentage
C	24	27%	65	73%
E_1	41	43%	54	57%
E_2	42	44%	54	56%

Number of Scorable Bombs. Similar to the first analysis, Chi-Square was used to test for significant differences in the number of scorable (circular error of 300 feet, or less) bombs delivered by the C and E groups. Again, the E groups were significantly better at the five percent level of confidence (χ^2=7.82). Table 2 lists the observed values and percentages for the three groups.

TABLE 2.

NUMBER OF SCORABLE BOMBS
(Training Effects Analysis)

	Scorable Number	Scorable Percentage	Misses Number	Misses Percentage
C	64	72%	25	28%
E_1	82	86%	13	14%
E_2	82	85%	14	15%

Bomb Circular Error. Using the circular error on bomb delivery tasks in the F-5B aircraft as the dependent variable, a Lindquist Type I analysis of variance was conducted to compare the C and E groups on this measure. The overall F value was significant at the five percent level of confidence (F=4.39) and a Tukey Multiple Comparison Test proved both E groups to be superior to the C group at the same level of confidence. There were no significant differences between the E_1 and E_2 groups. Table 3 lists the observed means for each group on the three bomb delivery tasks.

TABLE 3.

BOMB DELIVERY CIRCULAR ERROR MEANS
(Training Effects Analysis)

	10^0 dive angle	15^0 dive angle	30^0 dive angle
C	200'	180'	204'
E_1	148'	138'	169'
E_2	138'	144'	159'

Flying Performance Ratings. The same Lindquist Type I design was employed to analyze differences between the C and E groups where the dependent measure was Instructor Pilot rating of F-5B flying performance. Although the E groups ratings were superior to those assigned the C group at the 20 percent level of confidence, the F value was not significant at the five percent level (F=2.36). Table 4 lists the mean ratings received by each group on the three bomb delivery tasks.

TABLE 4.

FLYING PERFORMANCE RATING MEANS
(Training Effects Analysis)

	10^0 dive angle	15^0 dive angle	30^0 dive angle
C	44.6	48.9	49.4
E_1	52.7	52.7	48.3
E_2	49.4	52.2	51.1

Platform Motion Effects. Considerable effort was expended on the analyses of possible simulator platform motion effects. The results of all this may be summarized at the outset by stating that none were found. However, since the issue is an important one for device configuration, the lack of significant differences and the extreme closeness of the two experimental groups on the dependent measures were of interest.

In addition to the dependent variables previously used for C and E groups contrasts, the simulator data were also available for analysis. The approach taken followed this pattern, analyzing F-5B data first and simulator data second.

F-5B Data: Number of Qualifying Bombs. A Chi-Square Test performed on the data given in Table 1 found no significant differences between the E_1 and E_2 groups (χ^2=.01). In fact, when the hung bomb on one task is considered, the scores of the two groups are identical.

F-5B Data: Number of Scorable Bombs. A Chi-Square Test performed on the data given in Table 2 also showed no differences between the E_1 and E_2 groups (χ^2=.03). Again, allowing for the hung bomb in the E_1 group, the numbers are identical.

F-5B Data: Bomb Circular Error. The Lindquist Type I analysis of variance resulted in no significant differences (F=.06) between the means of the two experimental groups (see Table 3).

F-5B Data: Instructor Pilot Ratings of Flying Performance. As before, the analysis of variance produced no significant differences (F=.03) between the means of the E_1 and E_2 groups (see Table 4).

The analysis of the simulator training data for the motion and no-motion experimental groups also failed to yield significant differences. Four analyses were run on this data. The first analysis used bomb delivery circular error as the dependent variable and was performed to determine if there was an initial difference between the two groups. The second analysis used the same dependent variable and was conducted to see if the groups differed at the conclusion of their simulator training. The third and fourth analyses paralleled these initial and final comparisons but used aircraft delivery parameters (airspeed, heading, release altitude, G-load, and dive angle) as the dependent variables in a multivariate analysis of variance.

Initial Circular Error. A Lindquist Type I analysis of variance was performed on the observed average bomb delivery circular error recorded for each subject on his initial six attempts on each task (i.e., 10, 15, and 30 degree dive angle). The results showed no significant difference at the five percent level of confidence (F=.61). Table 5 lists the observed means for each group on the three bomb delivery tasks.

TABLE 5.

INITIAL BOMB DELIVERY CIRCULAR ERROR MEANS
(Motion Effects Analysis)

	10^0 dive angle	15^0 dive angle	30^0 dive angle
E_1	189'	175'	151'
E_2	151'	126'	159'

Final Circular Error. The same procedure was used to determine if the E_1 and E_2 groups final performance (eighth simulator mission) on these tasks differed significantly. At the five percent level of confidence,this was found not to be the case (F=.00). Table 6 lists the observed means for each group on the three bomb delivery tasks.

TABLE 6.

FINAL BOMB DELIVERY CIRCULAR ERROR MEANS
(Motion Effects Analysis)

	10^0 dive angle	15^0 dive angle	30^0 dive angle
E_1	107'	104'	129'
E_2	121'	86''	133'

Initial Attempts Aircraft Delivery Parameters. The basic "groups by tasks" design was employed for the multivariate analysis of variance performed on aircraft delivery parameters observed for the initial three simulator missions. Unlike the univariate cases, there were <u>five</u> dependent variables analyzed simultaneously. Rao's approximation of the F-distribution provided the test of significant (Tatsuoka, 1971). The result was an R-value of .28 which is not significant at the five percent level of confidence. The observed mean differences from the ideal value for each aircraft parameter are given in Table 7 for each experimental group and task.

Final Attempts Aircraft Delivery Parameters. The analysis of the aircraft delivery parameters observed on the eighth simulator mission was identical to that used above. As before, the test for significant differences was Rao's approximation of the F-distribution, and the result was an R-value of 1.63. This was not significant at the five percent level of confidence. The observed mean differences from the ideal value for each aircraft parameter are listed in Table 8 for each experimental group and task.

<u>Subject Ability Levels and Simulator Training.</u> It seemed reasonable to hypothesize that training in the ASPT would improve air-to-surface weapons delivery skills, but an interesting corollary question is: who profits most? Is such simulator training more advantageous for the novice pilot of superior ability or for the novice pilot of inferior ability? Six analyses were performed to answer this question. The first two of these analyses were based on data collected in the simulator; the second four used data collected during the aircraft sorties.

Simulator Data. Using the Lindquist I design, two univariate analyses of variance were conducted to determine whether ASPT training was more beneficial to the subjects rated as the upper one-half or the lower one-half of the class from lead-in training. For these analyses, bomb circular error served as the dependent variable.

The first analysis investigated the initial disparity in weapons delivery skills between the upper one-half and lower one-half groups. It was rather surprising to find that the groups did not differ significantly at the five percent level of confidence (F=.58). Table 9 gives the observed means for each group on the three bomb delivery tasks studied.

observed means for each group on the bomb delivery tasks.

TABLE 7.

INITIAL AIRCRAFT DELIVERY PARAMETERS (Motion Effects Analysis)

	10^{o} dive angle		15^{o} dive angle		30^{o} dive angle	
E_1	Heading	1.57^{o}	Heading	2.51^{o}	Heading	4.65^{o}
	Altitude	85.04'	Altitude	55.10'	Altitude	152.09'
	Airspeed	5.63 kts	Airspeed	5.95 kts	Airspeed	6.06 kts
	G-load	.18g	G-load	.22g	G-load	.31g
	Dive Angle	1.39^{o}	Dive Angle	1.05^{o}	Dive Angle	1.46^{o}
E_2	Heading	1.50^{o}	Heading	1.66^{o}	Heading	3.20^{o}
	Altitude	110.01'	Altitude	67.08'	Altitude	111.50'
	Airspeed	4.51 kts	Airspeed	7.55 kts	Airspeed	5.11 kts
	G-load	.14g	G-load	.18g	G-load	.33g
	Dive Angle	1.63^{o}	Dive Angle	$.83^{o}$	Dive Angle	1.12^{o}

TABLE 8.

FINAL AIRCRAFT DELIVERY PARAMETERS (Motion Effects Analysis)

	10^{o} dive angle		15^{o} dive angle		30^{o} dive angle	
E_1	Heading	1.39^{o}	Heading	1.85^{o}	Heading	3.21^{o}
	Altitude	82.61'	Altitude	98.71'	Altitude	117.57'
	Airspeed	3.37 kts	Airspeed	4.24 kts	Airspeed	7.16 kts
	G-load	.19g	G-load	.19g	G-load	.25g
	Dive Angle	2.02^{o}	Dive Angle	$.97^{o}$	Dive Angle	1.05^{o}
E_2	Heading	1.18^{o}	Heading	1.40^{o}	Heading	4.44^{o}
	Altitude	95.99'	Altitude	73.11'	Altitude	216.48'
	Airspeed	3.73 kts	Airspeed	8.00 kts	Airspeed	4.42 kts
	G-load	.07g	G-load	.15g	G-load	.26g
	Dive Angle	2.64^{o}	Dive Angle	1.09^{o}	Dive Angle	1.63^{o}

TABLE 9.

INITIAL BOMB DELIVERY CIRCULAR ERROR MEANS
(Student Ability Analysis)

	10^{o} dive angle	15^{o} dive angle	30^{o} dive angle
Upper 1/2	178'	114'	152'
Lower 1/2	174'	185'	158'

TABLE 10.

FINAL BOMB DELIVERY CIRCULAR ERROR MEANS
(Student Ability Analysis)

	10^{o} dive angle	15^{o} dive angle	30^{o} dive angle
Upper 1/2	86'	96'	110'
Lower 1/2	132'	94'	153'

At the conclusion of the simulator training, however, there was a definite difference in degree of skill shown by the two groups. The F-value equaled 3.14 and was significant at the five percent level of confidence with a directional hypothesis. Table 10 gives the observed means for each group on the bomb delivery tasks.

Aircraft Data. Four analyses were run using the data from the F-5B sorties as the dependent variables. The first analysis was a Chi-Square test on the number of qualifying bombs delivered by the two groups. The resulting Chi-Square

value of 1.57 was not significant at the five percent level of confidence (Table 11).

TABLE 11.

NUMBER OF QUALIFYING BOMBS
(Student Ability Analysis)

	Qualifying		Misses	
	Number	Percentage	Number	Percentage
Upper 1/2	46	48%	50	52%
Lower 1/2	37	39%	58	61%

The second analysis was essentially a repeat of the first, except that number of scorable bombs was used as the dependent variable. Again, the Chi-Square test was not significant at the five percent level of confidence (χ^2=1.16). Table 12 gives the observed values and percentages for the two groups.

TABLE 12.

NUMBER OF SCORABLE BOMBS
(Student Ability Analysis)

	Scorable		Misses	
	Number	Percentage	Number	Percentage
Upper 1/2	85	88%	11	12%
Lower 1/2	79	83%	16	17%

When bomb circular error was used as the dependent variable, the Lindquist Type I analysis of variance resulted in an F-value of .73 which was not significant at the five percent level of confidence. Table 13 gives the means for each group on the three bomb delivery tasks.

TABLE 13.

BOMB DELIVERY CIRCULAR ERROR MEANS
(Student Ability Analysis)

	10^0 dive angle	15^0 dive angle	30^0 dive angle
Upper 1/2	119'	162'	143'
Lower 1/2	154'	133'	184'

The same design was used to evaluate Instructor Pilot ratings of F-5B flying performance for the two groups. The resulting F-value of 1.22 was not significant at the five percent level of confidence. Table 14 lists the mean ratings received by each group on the three bomb delivery tasks.

TABLE 14.

FLYING PERFORMANCE RATING MEANS
(Student Ability Analysis)

	10^0 dive angle	15^0 dive angle	30^0 dive angle
Upper 1/2	52.7	51.1	52.7
Lower 1/2	49.4	53.8	46.7

The end result of these four analyses was that although none individually reached the five percent level of confidence, when viewed collectively, they offered strong evidence that it was the superior students who gained most from the simulator training. The outcomes of all four analyses were in the same direction. When the actual probability levels of the Chi-Square and F-test were taken into consideration, the level of confidence reached was beyond the five percent figure.

CONCLUSIONS

Because the study was so basic; its methodology so in conformance with typical Air Force training operations; and, the results so clearcut; there is little to be added to that already presented. Therefore, this section will consist of only a few brief statements summarizing simulator platform motion, and student ability as a variable in simulator training.

Simulator Training. The answer to the question, "Does generalized air-to-surface simulator weapons delivery training transfer to a specific aircraft?" is an unqualified yes. Perhaps the most important aspect of this result, in terms of its implications for simulator and training program design, is the fact that the ASPT was configured as a T-37 (with a sighting device) and still there was significant transfer of training to the F-5B. Although the finding that a low fidelity device can provide considerable training when properly employed is not new (Prophet and Boyd, 1970), the study was a rather striking confirmation of the point.

Platform Motion. It is impossible to prove the null hypothesis, but the results of the study show unequivocally that six degree of freedom platform motion did not enhance the training value of the simulator.

Considering the aerial weapons delivery task, this is not a surprising finding. The task is primarily visual, and motion (or movement) serves only as an alerting stimulus to the pilot.

This fact has significant ramifications for simulator design. The deletion of platform motion requirements for air-to-surface simulation would have enormous cost-avoidance consequences. It is believed that a G-seat and G-suit (with appropriate stick and pedal "shakers") would provide all necessary "motion" cues needed for this simulation.

Student Ability. In this study, it was the better novice pilot who profited the most from the ASPT training. The fact that the better student usually profits more when given minimal fixed amounts of practice and receives the greatest benefits from innovations in training and education is a fairly common observation. The same general finding also occurs even when the content of training program syllabus remains constant, but new media are introduced to convey this subject matter. That the present study was no exception to this general rule adds face validity to the results obtained.

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PLATFORM MOTION AND SIMULATOR TRAINING EFFECTIVENESS

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SUMMARY

Several recent studies reported that simulator motion did not benefit subsequent flight performance. Other studies have reported various effects of motion upon pilot performance in simulators. These possibly contradictory findings are examined in the light of recent distinctions made between maneuver and disturbance motion. The studies in which simulator motion did not benefit transfer predominantly employed maneuver motion cues, whereas the other group of studies incorporated more disturbance motion cues. Pilot reactions to simulator motion also were examined in terms of maneuver vs. disturbance motion, and it was noted that judgments of the training value of simulator motion were related to the maneuver-disturbance distinction. It is concluded that maneuver motion may be of little potential training value, under many circumstances, and data necessary to an adequate simulation of disturbance motion may not be available. An analysis of the training requirements associated with disturbance motion is needed.

MOTION AND TRANSFER OF TRAINING STUDIES

Although motion simulation represents a significant portion of the cost of simulator procurement and operation, the investigation of the influence of motion upon transfer of simulator training to operational aircraft has been largely ignored. There were a number of studies of simulator motion in relation to aircraft handling qualities and control during the 1950s and 1960s, but most of them addressed transfer of training only indirectly. The first significant published transfer of training study of the effectiveness of simulator motion upon subsequent performance in flight was reported in 1975 by Jacobs and Roscoe.

Jacobs and Roscoe reported that pilot performance in the aircraft did not benefit from the presence of normal washout cockpit motion in the simulator. In that study, training received in the GAT-2 in a two-axis (pitch and roll) normal washout motion condition, compared with training in the same device without motion, resulted in non-significant differences in amount of transfer to the aircraft for those two conditions. There was, however, significant positive transfer for both motion and no-motion conditions. Similar results have been obtained in a U.S. Air Force undergraduate pilot training study involving the more sophisticated six-axis motion system associated with the Advanced Simulator for Pilot Training (ASPT) (Woodruff, 1976).

MOTION AND SIMULATOR PERFORMANCE STUDIES

The findings in these two recent studies that the presence of motion did not increase simulator training effectiveness is of considerable interest, since there are other studies showing that, at least under some circumstances, motion does influence simulator training. For example, Fedderson (1962) reported a slight advantage in favor of a motion simulator trained group over a no-motion group during brief transfer trials hovering a helicopter. More importantly, perhaps, the motion group in his study reached asymptotic performance in the simulator more rapidly, suggesting that simulators with motion may provide more efficient training. A recent U.S. Air Force study of pilot responses to engine failure in a simulated transport-type aircraft found that training is more effective when motion is added to a simulator with a visual display than when the same simulator and visual are used without motion (DeBerg, McFarland, & Showalter, 1976).

Further, there is evidence that pilot performance differs as a function of the presence or absence of motion. For example, Perry and Naish (1964) found that pilots respond to external forcing functions such as side gusts more rapidly, with more authority, and in a more precise manner in a simulator with motion and visual cues than when only visual cues are present. NASA researchers (Rathert, Creer, & Sadoff, 1961) found that the correlation between pilot performance in an aircraft and in a simulator increased with the addition of simulator motion cues where such cues help the pilot in coping with a highly damped or unstable vehicle or a sluggish control system, or under some circumstances, where the control system is too sensitive. Where the aircraft is easy to fly, however, as is the case with the aircraft used in the Jacobs and Roscoe study (Piper Cherokee) and in the Air Force ASPT study (T-37), motion may have no effect.

In another NASA study (Douvillier, Turner, McLean, & Heinle, 1960) of the effects of simulator motion on pilot's performance of flight tracking tasks, the results from a moving base flight simulator resembled the results from flight much more than did those from a motionless simulator. In a British study, Huddleston and Rolfe (1971) reported that the presence of simulator motion produced patterns of control response more closely related to those employed in flight. That is, using simulators without motion, experienced pilots were able to achieve acceptable levels of performance, but their patterns of control response showed that their performance was achieved using a strategy different from that used in a dynamic training environment. Research at the University of Illinois related to instrument display design found that the quality of the simulator motion involved affected pilot responses to display types differentially, with inappropriate banking motions interfering with command flight path tracking (Ince, Williges, & Roscoe, 1975).

Thus, numerous studies provide evidence that the presence of motion, i.e., movement of the platform upon which the simulator cockpit rests, does affect performance in the simulator. Not only can motion affect learning rates, but the performance of the pilot in the presence of motion may be different than it would be in the absence of motion. With motion, his simulator control responses to external forcing functions appear to be more rapid and accurate and more like responses used to control the aircraft in flight. While it cannot be concluded from these studies that simulator motion during training will enhance subsequent performance in the aircraft, they do suggest that simulator motion can affect the acquisition of skills in the simulator. These effects of motion upon performance in the simulator have been demonstrated under controlled experimental conditions that tend to make it unlikely that the noted differences in performance could be attributed solely to factors other than the presence of motion during simulator training.

The influence of platform motion is not necessarily beneficial, however. Excessive or inappropriate motion, e.g., high levels of simulated turbulence, could make learning less rapid if it were a factor in making the simulator more difficult to control. Likewise, motion that is out of synchronization with visual or other cues could interfere with simulator control if it made trainees ill or presented misinformation to them. For example, it has been reported that the simulator used in the Air Force ASPT study cited above has time lags in the motion system that make the performance of some maneuvers difficult (Hutton, Burke, Englehart, Wilson, Romaglia, & Schneider, 1976).

MANEUVER MOTION VS. DISTURBANCE MOTION

In discussing the influence of motion upon pilot performance in simulators, Gundry (1976a, 1976b) distinguishes between two kinds of motion cues and suggests that they might affect performance differentially. Maneuver motion is that motion that arises within the control loop and results from pilot-initiated changes in the motion of the aircraft in order to change its heading, altitude, or attitude. Disturbance motion, on the other hand, arises outside the control loop and results from turbulence or from failure of a component of the airframe, equipment or engines that causes an unexpected (to the pilot) motion of the aircraft. Matheny (1976) made a similar distinction in a study in which he identified aircraft motion as resulting from either external forcing functions or input into the aircraft controls.

The reason that platform motion can result in quicker, more accurate simulator control probably is that the disturbance component of that motion resulting from simulated turbulence or equipment failure can provide more rapid and relevant alerting cues about forces acting upon the aircraft than could be obtained from other cues sources. Maneuver motion does not fulfill an alerting function, because it results from pilot-initiated control movements. Research involving maneuver motion, Gundry states, indicates that this component of platform motion has little effect upon the control of an aircraft whose flight dynamics are stable. For unstable vehicles, however, the presence of maneuver motion will allow the pilot to maintain control even in flight regions where control by visual cues alone would be impossible. Thus, disturbance motion permits more rapid and accurate aircraft control under all flight conditons in which such motion is appropriate. Maneuver motion, however, improves aircraft control only when the aircraft is unstable.

In both the Jacobs and Roscoe and the Air Force ASPT studies cited above, emphasis was upon simulation of maneuver rather than disturbance motion. Since maneuver motion is pilot induced and the aircraft involved in these studies were quite stable, the most likely role of motion was to provide feedback to the pilot. If sufficient feedback were available from other sources such as the aircraft instruments or an extra-cockpit visual display, as likely was the case, the maneuver motion provided in these two studies could not be expected to have a large effect upon simulator training effectiveness, and probably would be ignored altogether by the trainees. Had these two studies examined the influence of disturbance motion resulting

from factors outside the control loop, e.g., malfunctions, the results might have been different.

The evidence that disturbance motion may have a large effect upon pilot performance in the simulator and upon his subsequent performance in the aircraft should not be overlooked by personnel making decisions concerning the importance of platform motion in aircraft simulator training. The fact that the influence of such motion was not apparent in two recent transfer of training studies is probably attributable to the absence of a significant disturbance component to the motion involved in those studies. The maneuver motion that was present appears not to have been a significant factor in transfer of training for the undergraduate level trainee in the relatively stable aircraft involved in these studies.

PILOT PERCEPTIONS OF MANEUVER AND DISTURBANCE CUES

The author recently had occasion to examine four Air Force simulator training programs in which simulators with motion were employed. The simulators were the C-5A, the FB-111B, the F-4D and E, and the A-7E. Although the contribution of motion to the effectiveness of the combat crew training and continuation training activities in which these simulators are used has not been investigated empirically, the perceived value of the platform motion cues they provide was discussed with Air Force pilots and instructors who participate in that training. Many of these personnel held strong opinions concerning the probable value of motion. While those opinions were predominantly favorable, there were a few unfavorable ones as well. In all cases, whether favorable or unfavorable, the basis for the opinions expressed was explored by the investigator.

Favorable opinions were difficult to relate to specific aspects of motion simulation and in many cases were considered to be endorsements of the general idea that simulator motion is important because the aircraft moves. Those who were the most enthusiastic in their opinions favoring motion cited motion characteristics of the disturbance type as the primary basis for their positive views, i.e., motions associated with equipment failure, weapons release, buffet and turbulence. Very few pilots expressed strong positive feelings toward maneuver motion -- it contributed to realism but was not cited as specifically related to particular training goals.

The relatively few negative opinions expressed concerning motion were all strongly held, and they involved both maneuver and disturbance motion. In one simulator in which maneuver motion cues lagged noticeably behind instrument displays and tended to be jerky rather than smooth, the motion was viewed as annoying, and pilots using that particular device preferred to train with the motion system inoperative. Apparently, maneuver motion can have little positive value in most simulator training programs, but it can have a negative influence, at least upon pilot attitudes, if it is not representative of comparable motion in the aircraft, e.g., if it lags noticeably the pilot's control input or the cues provided by instruments or visual displays.

Most of the negative comments received during the interviews could be related to disturbance motion -- or, more precisely, to the absence of disturbance motion cues that the pilots knew to be characteristic of the aircraft simulated. Two examples of this situation were noted, one involving the A-7D simulator and the other involving the C-5A simulator.

A critical condition involving the A-7D aircraft is that labeled "Departure." It is a high angle of attack condition in which the aircraft yaws abruptly and enters an uncontrollable spin. The yaw in this case is a disturbance cue that alerts the pilot to the condition's onset. Training in recovery from the departure is considered of critical importance, but such training in the single-place aircraft is not included in A-7D training for reasons of flight safety. Attempts to provide the desired training in the A-7D simulator have been unsuccessful, reportedly because the yaw motion cues cannot be simulated in that device (it lacks the yaw motion axis).

The A-7D manufacturer has a research simulator, called LAMBS (for Large Amplitude Motion Base Simulator), in which the departure can be simulated with the yaw motion component. All Air Force A-7D pilots have undergone departure recovery training in LAMBS. Pilots who have previously experienced a departure in the aircraft have reported that its simulation in LAMBS is "realistic." Pilots who received training in LAMBS and subsequently experienced a departure in the aircraft credit the motion simulator training for the ease with which they were able to reestablish aircraft control, although such reports are purely subjective. In any event, the yaw disturbance cue provided by LAMBS is well received by Air Force A-7 pilots, whereas the absence of that cue in the Air Force simulator renders departure recovery training in it unacceptable.

One of the A-7D pilots interviewed had recently flown the Navy's A-7E simulator

that has a six-axis motion system. That pilot expressed a highly favorable opinion concerning A-7D simulator training. While there are a number of differences in these two simulators and the manner in which they are used, the extent of motion simulation was singled out as an important difference between the two devices which, in the opinion of that particular pilot, influences training.

The C-5A simulator motion platform, like that of the A-7D, lacks the yaw axis, so the yaw disturbance motion associated with loss of an engine cannot be simulated. Pilots associated with C-5A training at Altus AFB cited this deficiency in the simulator as a negative factor in determining the effectiveness of simulator training for engine losses at low altitude. It was not cited as a factor in other training operations, including operations that involve yaw maneuver motion, however. Thus, where yaw could be considered a disturbance motion, it was perceived by these pilots to be needed for training; where it could be considered a maneuver motion, it was not perceived as important.

The C-5 simulator described above has a visual display, and the yaw of the aircraft associated with engine loss is reflected in the visual scene. The pilots indicated that the visual yaw cue alone was insufficient, in their opinion, when engine loss occurred during landing and takeoff maneuvers. They felt that pilots in the simulator responding to visual cues were much slower in initiating corrective action than they were in the aircraft where motion provides an early and more pronounced alert that a disturbance has occurred.

DISCUSSION

The influence of platform motion upon transfer of simulator training has not been clearly established by the data available at the present time. It has been demonstrated that motion can affect pilot performance in the simulator in ways that may make his performance in the simulator more like his performance in the aircraft, but it has not been shown that simulator motion enhances his subsequent performance in the aircraft. The two studies that have addressed the question of transfer directly did not support a conclusion that motion is needed. Likewise, there is no consensus among pilots as to the need for motion in simulator training.

The distinction between maneuver and disturbance motion is useful in attempting to understand both the prior research on motion and the reactions of pilots to the motion component of aircraft simulators. In the transfer of training studies in which motion did not appear to influence subsequent pilot performance, the motion involved was predominantly, if not exclusively, of the maneuver variety. On the other hand, disturbance motion was the predominant type of motion in studies in which changes in pilot performance were related to motion simulation. Thus, the results of both sets of studies can be accepted and attributed to the nature of the motion simulation involved in each. Disturbance motion is important, at least in training situations where disturbance cues can be related to specific training objectives and when the aircraft simulated is unstable or is particularly responsive to control input. Maneuver motion may be important also under some circumstances, but the evidence available at this time has not shown that it contributes to transfer of training in easy-to-fly aircraft with undergraduate level trainees.

More attention has been paid in the design of training simulators to maneuver motion than to disturbance motion. Emphasis has been upon providing in a simulator the motion cues associated with well-coordinated pilot control inputs, scaled down to the limits of travel and accelerations of the motion platform. Since most training and operational aircraft are relatively stable and easy to control in flight, this kind of motion simulation may be of very little potential value in training. It might be more beneficial from the training standpoint to provide the motion cues associated with disturbances to the aircraft not originated by the pilot, and then only at their initial onset values, so that the pilot can learn to respond specifically to such cues rather than learning to respond to visual or other cues that occur later in time.

Because the distinction between maneuver and disturbance motion has only recently been articulated, there has been little opportunity to examine systematically the influence of each upon simulator training effectiveness. Most prior training research on motion appears to have dealt primarily with maneuver motion, and maneuver motion appears reasonably well represented in the newer simulators, although time lags between pilot manipulation of aircraft controls and motion system responses have been a major problem in some of them. Disturbance motion has been less thoroughly investigated, and it is poorly or incompletely represented in many newer simulators. In fact, data on disturbance motion cues generally have not been developed and consequently are not available to motion system designers.

Additional research upon the role of disturbance motion in training is clearly needed. Emphasis in such research should be three-fold: (1) analysis of requirements for disturbance motion cues associated with

specific simulator training objectives; (2) development of models for the representation of critical components of such motion in simulators; and (3) determination of the effects on transfer of training of the presence and absence of such motion.

Because of the continuing concern over the costs associated with motion simulation, future research on motion simulation should also examine the use of platform motion systems with limited axes of motion, g-suits and seats, and "seat shakers" to determine whether the disturbance cues found to be important in training can be represented adequately in such relatively low cost motion devices. In any event, future motion system designs should be responsive to requirements to provide specific movements which cue specific pilot responses rather than to provide motions which simply correspond to motions of the simulated aircraft.

The real issue in simulator motion system design is the relating of motion cues to required pilot responses. What are the motion cues to which a pilot responds during flight? What discriminations must he make among them? How do they affect his performance? How can they be provided economically?

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ARMOR TRAINING DEVICE REQUIREMENTS

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The training environment in Armor Units, as in other units, appears to be fairly hostile in the eyes of the unit commander. To varying extents, they are faced with shortages of time, money, space, equipment, operating resources of fuel and ammunition, and trained leaders. Personnel turnover complicates the already serious situation. These problems make it difficult for Armor leaders to live up to the now familiar, but critical, imperatives in these slogans:

Win the first battle of the next war!

Fight outnumbered and win!

Fire fast, first!

Progress is being made in training. New Army Training and Evaluation Programs, Soldiers Manuals, and Skill Qualification Tests, to name a few things, have been produced and fielded. These are based on critical missions and tasks with corresponding conditions and standards that units must meet year round. Yet the realities of range availability, time, ammunition, and dollar constraints still force Armor units into cyclic participation in and evaluation of main gun firings and combined arms tactical exercises.

The result approximates a sine curve of proficiency peaks and valleys showing the fluctuation in meeting the minimum proficiency standards expressed in current soldiers manuals and Army training and evaluation programs. We feel the sine curve of proficiency must be leveled and that the minimum proficiency standard must be raised as well if we are indeed to win the first battle of the next war outnumbered. We hope to achieve this higher and more constant level of proficiency through the increased use of training devices and training simulation systems in addition to continuing to upgrade the balance of the training package.

Today there are very few training devices available. Most of them are oriented on individual tasks and are primarily used at our major institutions. Those devices which are in the field are either very primitive in terms of their training capability, or are just recently being received by Armor units. To resolve the problem, the Armor School has developed a three phase strategy and training device requirements plan to upgrade the proficiency and to reduce the resources a unit currently expends during tank gunnery training and individual crew qualification.

The first phase of our strategy, now training and through 1979, is centered around the significant revisions of our new tank gunnery manual, FM 17-12. Our immediate emphasis is on substituting main gun firing with subcaliber devices on reduced scale ranges. (A subcaliber device is one which allows a smaller projectile to fire instead of a main gun round.) This allows more firing to be done for less money and in smaller training areas. One major result of these devices and the new FM 17-12 is a 40% reduction in main tank gun rounds required to be fired during annual tank gunnery qualification. Another is the ability to provide more training right where the soldiers are located instead of moving to a larger training area. This is an important step if we expect to be able to keep our soldiers and units proficient on a year-round basis. One of the more significant devices to be included in our requirements plan and to be developed in this first phase is a TV camera system for gunnery training called the Tank Appended Crew Evaluation Device. It will present to an instructor a view of the gunner's sight picture so that scoring will not be as subjective as in the past and so that correction of sighting errors can be made. The sight picture as well as a frontal view of the target from an overview camera, timing information, and all crew member verbal exchanges are recorded. This allows objective after-action review and critique with the gunner and tank commander reviewing their own results. This device should significantly improve on-the-tank training, whether with dry fire, subcaliber fire or service ammunition.

Other training devices are also planned for introduction near the end of this phase and requirements have been developed for them. One is a unit level gunnery or conduct of fire trainer for each of the current tanks. This will allow gunner and tank commander skills to be sharpened and maintained off the tank and in the garrison area of the tank company. It will provide training in precision gunnery techinques with all the tank's fire control equipment against varied and multiple targets in many visibility conditions. Simulated tracers for both the machineguns and main gun will be provided as well as a burst-on-target projection for main gun hits. Hits and misses will be recorded for evaluation purposes.

Additionally, trainers for the loader of each tank are being developed. The loader has a physically difficult and dangerous job when the tank is firing on the move with stabilized gunnery. Not only is the tank itself moving, but the breech of the gun is in constant motion while it maintains the line of sight. This, coupled with recoil, a floor littered with shell casings, and the sheer weight of the projectiles makes it absolutely necessary for the loader to be adequately trained if the tank is to be used to its full potential of firing on the move. Currently, the only training in loading the main gun which the loader gets is in conjunction with actual fire. The loader trainer is envisioned for use at the battalion level and in the school environment.

Phase II of the Armor Training Device Strategy covers the period from 1980 through 1984. It will begin with a second edition of our gunnery manual. In addition, our soldiers manuals, skill qualification tests, and Army training and evaluation programs will be changed to reflect the increased training capabilities and training standards provided through the use of simulation devices. In this phase, a greater percentage of main gun ammunition will be allocated to platoon and company collective gunnery. We hope to be able to provide almost all individual and single crew gunnery training by simulation.

At the beginning of this phase, we expect to receive at Fort Knox an especially significant item of simulation equipment; the Armor Full Crew Interaction Simulator. It will be a one-of-a-kind test bed for the general-purpose of evaluating simulation technology and its potential application in training tank crews and also for the specific purpose of evaluating the concept of the Full Crew Interaction Simulator itself - full crew training in a totally simulated environment. This test bed will be developed from present technology available in flight simulators and foreign driver trainers, and will consist of modules for each crew position.

A significant feature of the Armor Full Crew Interaction Simulator will be the ability to turn on and off various cues and functions of the simulation system. This will assist in evaluating which cues, in terms of audio, visual, and motion, and which functions, in terms of gunnery controls and driver controls, are necessary to train crew members in either the individual or full crew training environments. All equipment at each crew position will have the same cues, functions, and physical appearance as the actual tank. The visual presentation of the simulated battlefield will be as realistic as possible. It will have multiple target arrays, hostile targets which can fire back, and battlefield obscuration, which includes smoke screens and the effects of artillery. For control and evaluation purposes, the instructor will have the capability of selecting the initial engagement parameters and target scenes, and of injecting malfunctions such as misfires and fire control system failures. This feature is designed to test the utility of the various functions.

The simulator will further be used for establishing crew selection criteria, for evaluating engagement and evasion techniques, and to validate training standards under variable conditions. The variable conditions can be electronic warfare, nuclear, biological or chemical environments, or difficult terrain, weather and visibility conditions. If testing proves the system to be effective, firm requirements for mobile full crew simulators will be submitted. In effect, the test bed has the potential to serve as the first operational/developmental test for the proposed XM1 and M60A3 full crew interaction simulators.

The test bed just described is only one of many developments to be made available in this phase. Another significant system will be the Tank Weapons Gunnery Simulation System (TWGSS). Basically, the TWGSS will provide realistic simulated precision gunnery training for the tank commander and gunner on the tank, exercising the driver also and, to a lesser extent, the loader. Precision gunnery is emphasized to avoid confusion with the simpler gunnery aspects of the Multiple Integrated Laser Engagement System (MILES) which is primarily a tactical training system and uses strictly line-of-sight gunnery. Elevation and lead angle, for example, are not accounted for in the MILES system. TWGSS will allow individual crew gunnery tables to be fired by simulation while on the actual vehicle thus permitting the shifting of live ammunition usage to platoon and company firing. This will permit platoon and company battleruns to be simulated in practice prior to live firing.

The TWGSS integrates the entire tank weapons system with simulation to provide for training in the acquisition and engagement of, and adjustment of fire upon, stationary and moving targets from either a stationary or moving firing tank. For the main gun, the system will superimpose a simulated burst in real-time over the calculated impact point in the gunner's sight, as well as provide tracer burn and, through interface with another device, flash, bang, and smoke. The same display is presented to the tank commander.

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Machinegun simulation will also be provided in conjunction with separately developed blank firing adapters. Machinegun tracers will appear in the sights to allow bursts to be "walked in" to the target. For gunnery proficiency evaluation purposes, the system will have record/playback and real-time audio and video media plus hits and numbers-of-rounds expended counters. All verbal exchanges as well as the gunner's sight picture will be recorded.

TWGSS will operate with both daylight and night sights and the thermal sight. It will also be interoperable with new target systems in development and an eye-safe training device for the laser range finder. Based on the success of this first stage as described, it is planned that the system be expanded to provide for up to battalion level force-on-force exercises with precision gunnery engagements.

In conjunction with the unit level conduct of fire trainer to be issued in Phase I, the Tank Weapons Gunnery Simulation System will go far toward leveling the peaks and valleys of gunnery proficiency by providing a system for realistic, year-round precision gunnery training. TWGSS will be able to develop, maintain, and objectively evaluate individual and crew proficiency in all tank gunnery skills without the use of live ammunition or dedicated range facilities. It will, as a result, provide a highly increased training capability using the same or less resources than at present. The projected operational date is mid-1982.

Related to this system, as was mentioned, is the Eye-Safe Laser Range Finder Training Device. This device, planned for late 1981, will provide for the safe use of the laser range finder during force-on-force engagements, but just as important will be its value in training laser range finder operators. The characteristics of current laser range finders often cause multiple returns to be received, forcing the operator to either make a choice between them or re-range. Stringent safety requirements now greatly restrict the practice necessary to reduce the occurrence of multiple returns and to make correct choices from among them when they do occur. The training device will either be a complete simulation of or an attachment to the actual laser range finder.

Training in tactics will also receive a big boost during this phase with the introduction of the Multiple Integrated Laser Engagement System (MILES). When the forerunner of MILES, REALTRAIN, was implemented in Europe, tests showed large increases in capability of an armored platoon after the third week of training when compared to the results of the platoon at the end of their first week. The dictum "fire fast, first" is going to be accomplished if these results are any indication, and we believe they are: a 55% increase in first detections of the "enemy" and a 153% increase in first engagements of the enemy. This is reflected also in a 26% increase in tank survivability and a 49% increase in tank killing prowess. Although these are only initial results, they point to what we can expect MILES to provide. REALTRAIN can only be used effectively at the platoon level, because of the extensive controller network required. With MILES, an entire battalion can be trained. Scoring objectivity will rise with the use of automatic equipment triggered by simulated fire and, at the same time, manpower resources will be conserved as controller density and training requirements will be lowered.

The new XM1 tank will be fielded near the beginning of this second phase of our plan along with a set of training devices for institutional and unit use. A conduct of fire gunnery trainer and a loader trainer, much as described for the other tanks, will be fielded for unit use. The large training centers will have two other trainers designed to increase the student to instructor ratio. A ten-station conduct of fire gunnery trainer and a five-station driver trainer are in development, each of which will only require one instructor. The gunnery trainer will be slightly more limited than the unit level model in that it will only train the gunner and not the tank commander. The driver trainer will be basically a procedures trainer with a series of preprogrammed visual presentations synchronized with student responses.

In addition to the gunnery and tactics simulators, we also have an urgent need to increase the effectiveness of our main gun firing by providing an improved target system, the Remoted Target System (RETS), which should be available in 1982. The Remoted Target System will have remotely controlled, automatically scored, portable pop-up and pop-down stationary targets and free roving, remotely controlled moving targets. This system should significantly increase the effectiveness of main gun firing by providing realistic targets, reliable machineguns, and automatic scoring.

The devices in this phase will provide the ability to perform individual and most crew training with a very high-level of realism. Perhaps a more important factor will be the higher level of availability to the trainer. By the end of Phase II, our initial sine curve should be flattening out and the actual

proficiency line should be getting closer to the proficiency of the future.

Phase III will begin with a third edition of the tank gunnery manual. It will be updated to include the new gunnery training strategy and gunnery exercises made possible through increased use of simulators and devices. Other training literature and tests will also have to be updated to reflect the increased training capabilities and new training standards. One of our major goals is to shift all main gun firings to the platoon and company levels, where we feel we will gain the greatest training payoff. This goal should be realized by the end of this phase. We will still require main gun firing of the gunnery tables at Fort Knox to train entry level Armor crewmen.

Phase III, 1985 to 1990, should realize the complete integration of all Phase II training devices into the Armor training program. In addition, two new training capabilities should be added. The Tank Weapons Gunnery Simulation System will be expanded to include a force-on-force capability. It will be the follow-on to MILES for armor and will allow the complete integration of precision gunnery with tactical training. It will require the tank crew to perform all its duties correctly in order to achieve a kill on the simulated battlefield and not just point the gun and fire.

Also, based on the full crew simulator test bed results, we plan to issue a mobile full crew interaction simulator for both the XM1 and M60A3 tanks to be used at the battalion level. The mobile Full Crew Interaction Simulator (FCIS) should provide the crew the most realistic training available, short of actual combat, and provide it on a year-around basis. The following items show a rough analysis of what a full crew interaction simulator might mean to a battalion in terms of engagements available and potential cost avoidance.

- Assumptions

  40 hr training week, 48 weeks/year

  54 tanks per battalion

  1 engagement every 3 minutes

  15 year life cycle for the simulator

  #3 Mil initial procurement cost

  $200K per year operating cost

- Crew training hours available on FCIS: 35:56 hr/crew/yr
- Available engagements per year on FCIS: 711 engage/crew/yr
- Available simulated mileage (10 MPH) per year: 355.6 miles/crew/yr
- Current cost per crew to fire gunnery tables: $36,928
- Current cost per mile to operate M60A1 tank: $15.15
- Mileage driven during annual gunnery (Europe): 500 miles
- Total cost per battalion for one year: $2.43 mil
- Total cost per battalion for 15 years: $36.45 mil
- Total cost with 6% inflation: $50.9 mil
- 15 year life-cycle cost of an FCIS: $6.0 mil
- Available for platoon, company and battalion collective live fire gunnery training: $44.9 mil

These Phase III devices would actually permit full simulation of all gunnery training, no matter what the level. However, we are firmly convinced that our troops must engage in live fire exercises if they are to maximize the weapons system effectiveness of the tanks. We are also convinced that this live fire should be accomplished during the collective training of our platoons, companies, and battalions. The overall payoff will be realized in increased unit readiness. While we intend for ammunition saved through simulation to be expended in collective firing, the development of these systems will permit us an alternative to live fire in the future, should resources become drastically reduced. The devices developed in each phase will be retained for the next phase ensuring continued training should any part of our development effort suffer setbacks.

Training requirements documents to support the devices described and other, supporting devices, have been submitted to the US Army Training Support Center. Through them, we are working with the Army Project Manager for Training Devices to implement our plan. Each device is now in some stage of development and funding.

ABOUT THE AUTHOR

CAPTAIN STEVEN O. VANDAL is a Project Officer in the Simulation and Devices Branch of the US Army Armor School, Directorate of Training Developments, Fort Knox, Kentucky. His background includes service as an armored cavalry platoon leader in Europe. Since January 1975, he has been deeply involved, from the user end, in managing the conception and development of Armor Training Devices. Captain Vandal is a graduate of the US Military Academy at West Point.

PATRIOT DISPLAY AND CONTROL SIMULATION

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SUMMARY

This paper presents a description of the US Army Human Engineering Laboratory (USAHEL) simulation and operator performance testing of the display and control subsystem of the PATRIOT Missile System.

INTRODUCTION: During the last 3 years an effort was undertaken by the HEL to develop a Command and Control Simulation Facility for the purpose of evaluating a variety of Display and Control (D&C) concepts and designs which are a vital part of today's complex military systems. The PATRIOT D&C subsystem is one of those systems currently being studied.

To begin with (Figure 1), I will give you an unclassified overview of the PATRIOT Missile System currently in development. Then I plan to talk about the PATRIOT's Display and Control Subsystem which HEL has simulated, the operator performance testing conducted for improving the D&C operator-machine interface design. Then I'll describe how we are currently using the PATRIOT simulator and some future tests that we plan to do.

PATRIOT System Overview:

The PATRIOT Missile System (Figure 2) is a new-generation Air Defense Weapon System now in development. The unique features of the system are a multifunction phased array radar, the track-via-missile guidance system and automated operation with human control.

In PATRIOT, a single multifunction radar performs all the tactical functions that, in present systems, require up to five separate radars; namely, airspace surveillance and detection, target tracking, identification, missile tracking and guidance and counter measures.

The track-via-missile guidance is the second major feature. It combines command guidance with homing guidance and, at the same time, provides for future adaptability to the changing threat by locating guidance processing in the ground equipment in software. This permits later changes, if necessary, to respond to threat changes without expensive hardware modifications to the missile. Automated operation is the third major feature which provides a basis for the system's firepower, effectiveness and reduced operating and maintenance costs. The central computer, monitored by operators, controls the operations of the complete PATRIOT Firing Platoon and monitors equipment status and locates faults for repair by replacement.

Finally, let's look at (Figure 3) the major equipment items comprising a PATRIOT Firing Platoon. The Firing Platoon consists of five major items: the radar set, the engagement control station and the electric power plant constitute the Fire Control Section, while five launching stations each including four missiles constitute the Launching Section. I should emphasize at this time that once the system is emplaced and operating, only the engagement control station is manned during air defense missions; all other items are remotely controlled and unattended.

Figure 4 shows a view of the engagement control station which is where human control is exercised. Stored computer programs, as modified by operator selections and instructions imputted on either of the two operator consoles, control the entire system operation.

Figure 5 shows the contractor's display and control consoles and Figure 6 shows one of the two consoles which have been simulated by the HEL. Since they are universal consoles, either console can be used by an operator to perform all functions or the functions can be divided between the two consoles in various ways; e.g., engagement control on one console and battalion interface and status monitoring on the other console.

HEL's PATRIOT D&C Simulation Overview

Briefly, the HEL simulation facility equipment consists of a Varian 620/f-100 minicomputer with 32K memory, a real-time clock and disc storage capability, plus an IDIIOM graphic-display system with up to four cathode ray tubes, function keyboards, light pens and tracking joysticks. Peripheral equipment includes a printer, teletype and card reader.

The computer programs are written in FORTRAN IV and are structured for making easy modifications to the basic console displays and control functions. The software programs developed for this simulation are divided into three categories (see Figure 7).

1. PATRIOT System overview.

2. HEL's PATRIOT Display and Control Simulation.

3. Operator Performance Testing.

4. Current use of the Display and Control Simulation and future testing.

Figure 1. Topics Presented

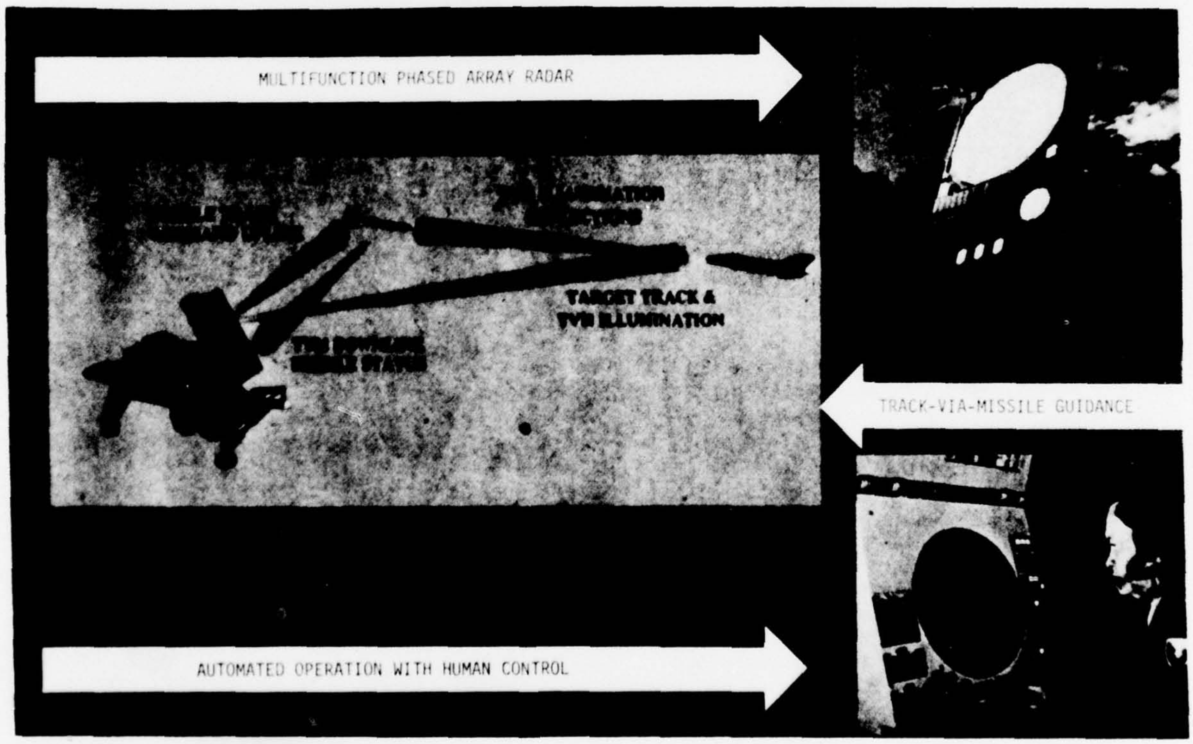


Figure 2. Essence of PATRIOT Missile System

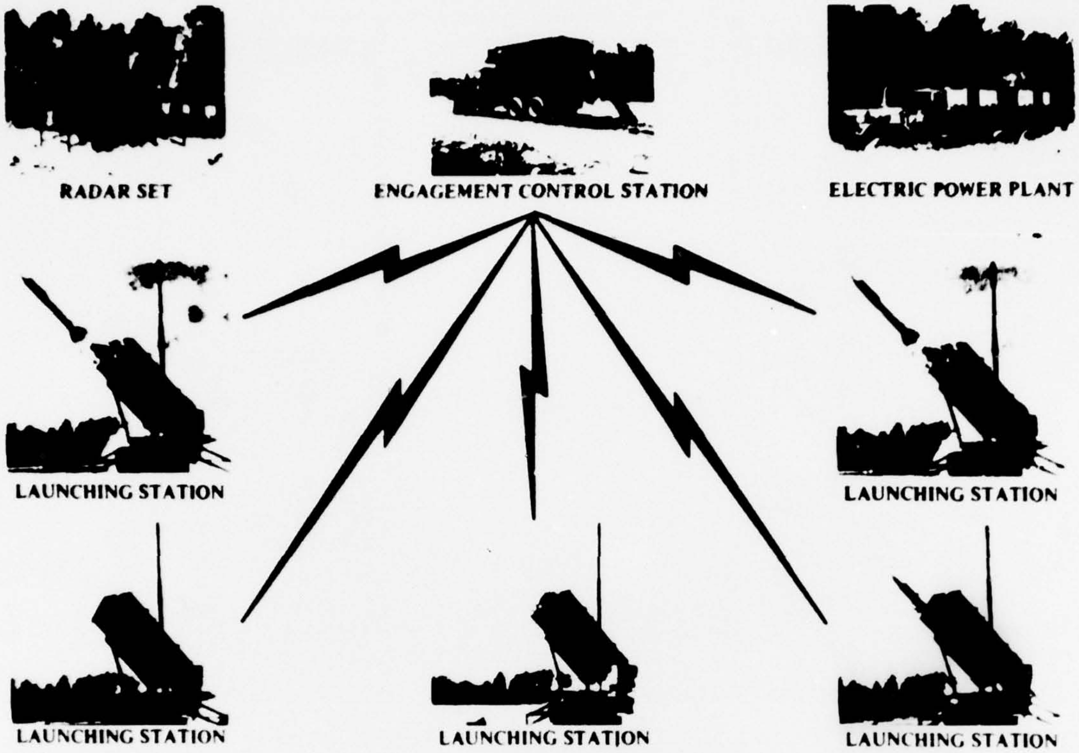


Figure 3. PATRIOT Firing Platoon

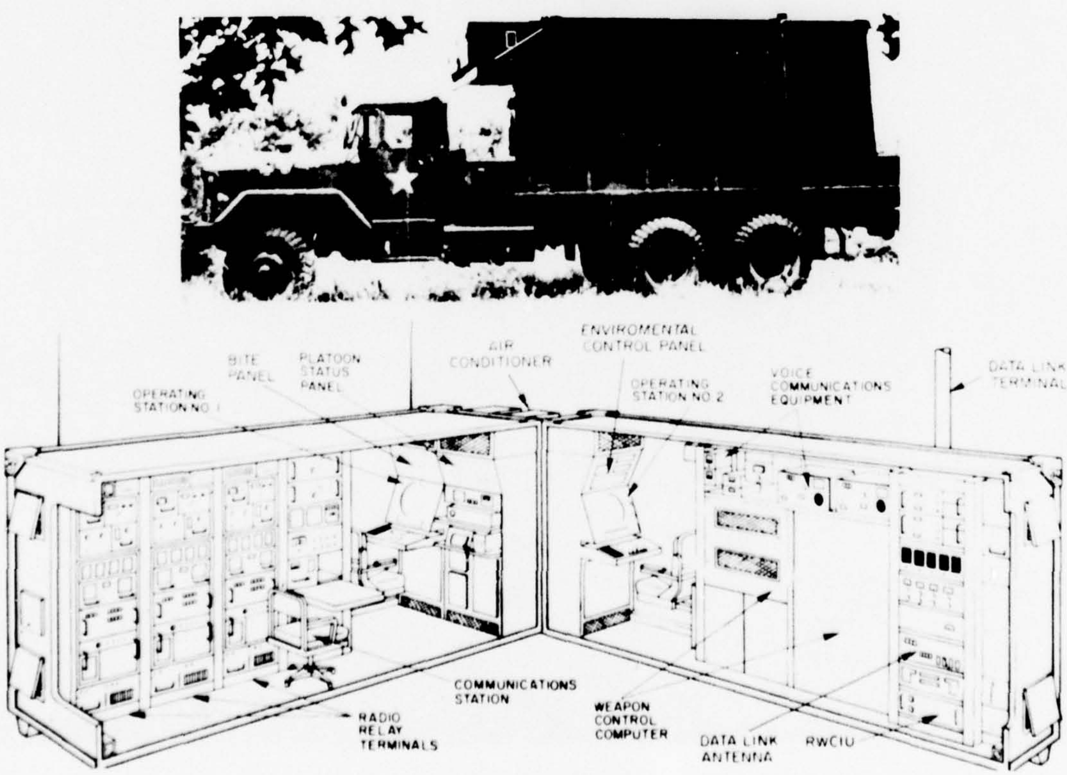


Figure 4. Engagement Control Station

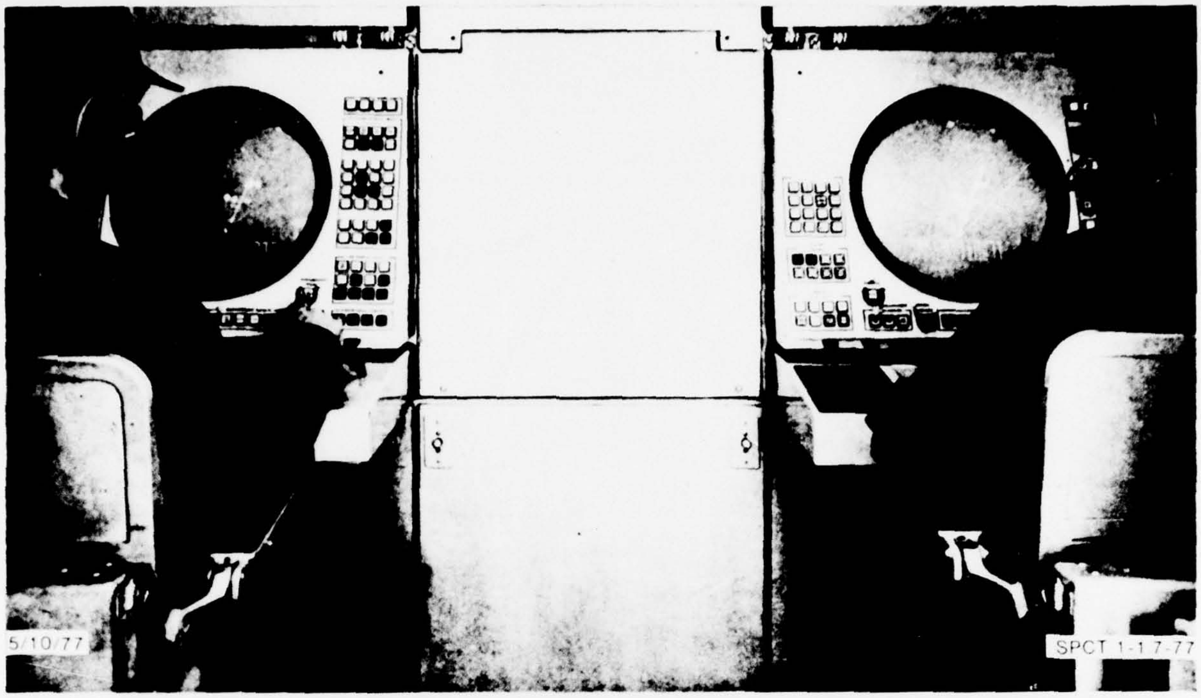


Figure 5. PATRIOT Display and Control Consoles

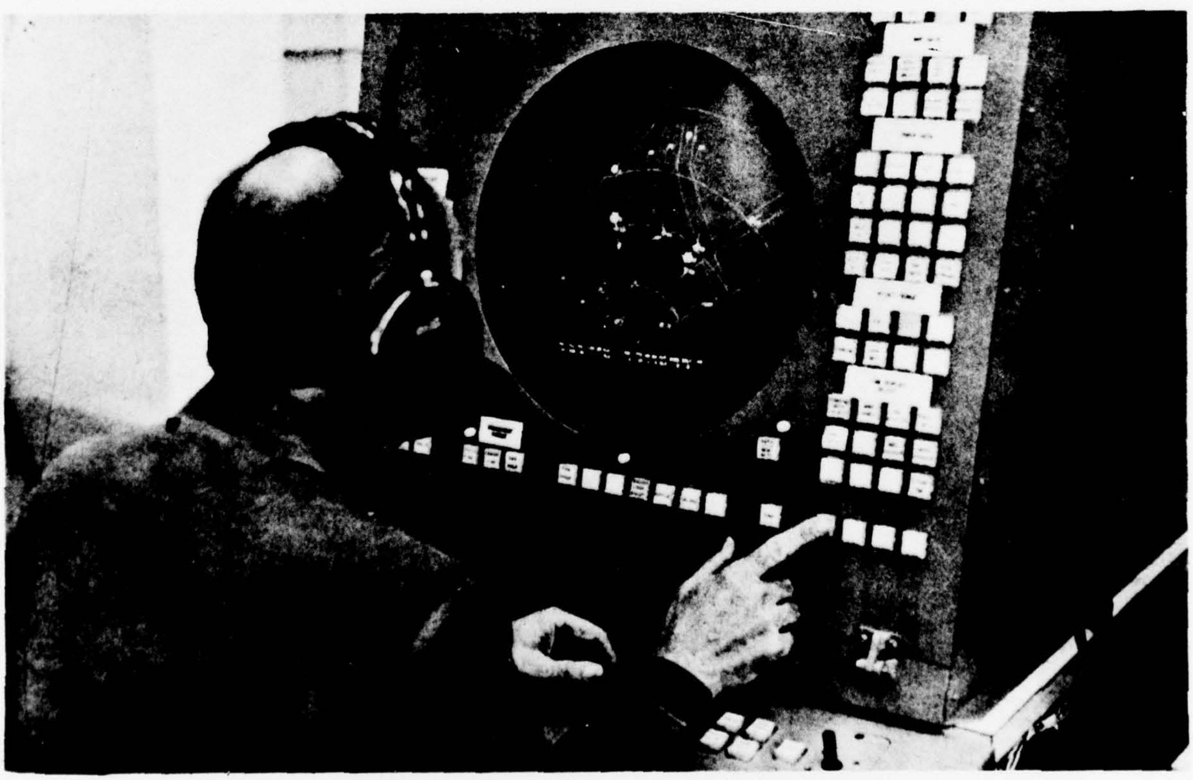


Figure 6. HEL's PATRIOT Display and Control Console Simulator

1. Preprocessing of target-scenario data.

2. Real-time radar display simulation.

3. Data analysis and operator-performance assessment.

Figure 7. Software Program Categories

The capability to preprocess target information relieves the computer of considerable arithmetic during program execution and permits preparing and checking a variety of scenarios prior to actual testing. For later access, preprocessed scenario data are stored on the disc. A scenario can contain up to 54 tracks plus a maximum of 45 target maneuvers.

The real-time simulation program uses the preprocessed scenario data to present a realistic display of aerial targets to the console operator. The target data interact with the operator's actions to simulate the total air-defense system. Operator actions and target events are recorded in real-time for later analysis.

Computer programs have been developed to aid in evaluating operator performance by isolating performance parameters and summarizing operator actions. There are also provisions for scenario replay with operator actions, individual target history, chronological event listing, target kill-assessment summary with intercept locations, asset boundary--penetration summary, and keyboard-action summary.

The PATRIOT Display and Control Simulation closely follows the actual system's current specifications for the displays, controls and fire control processes.

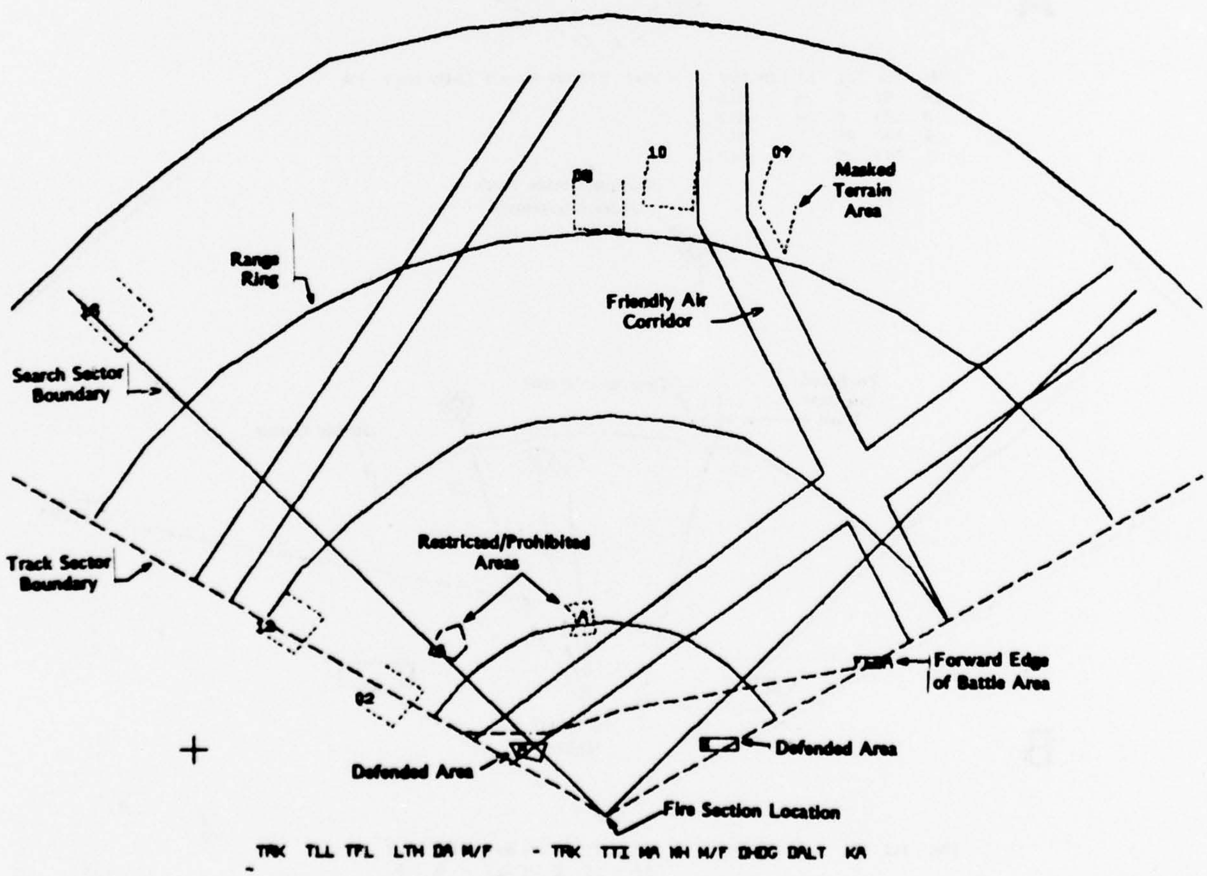
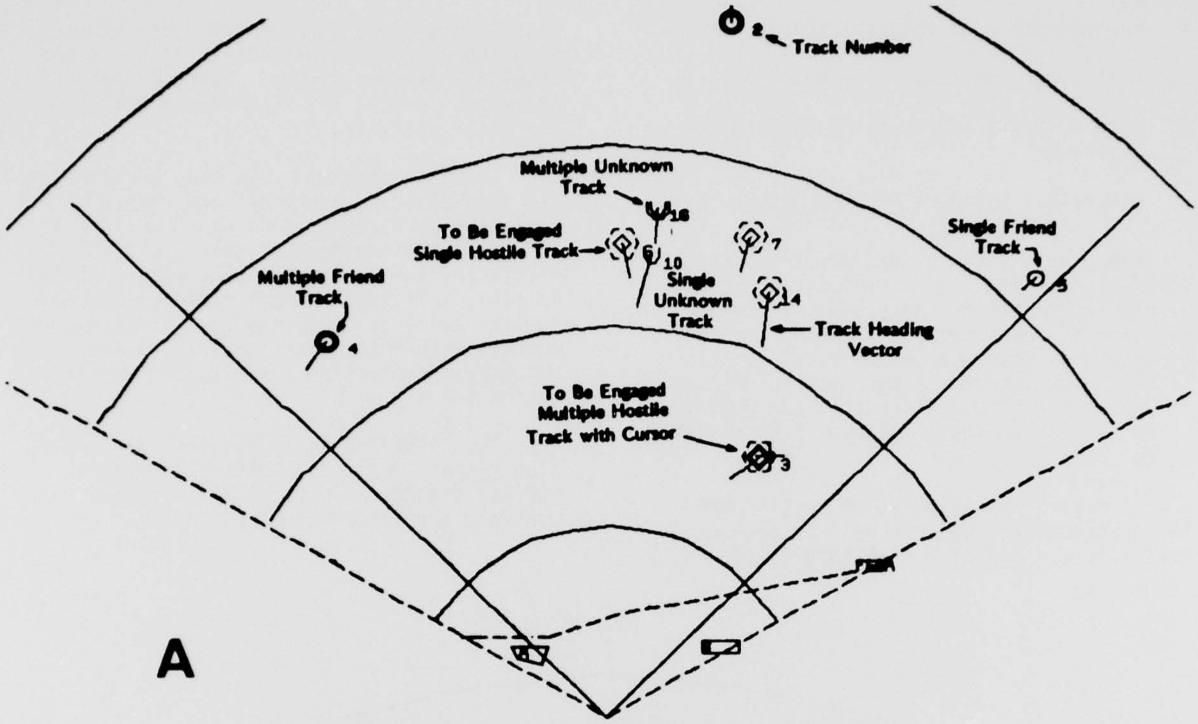
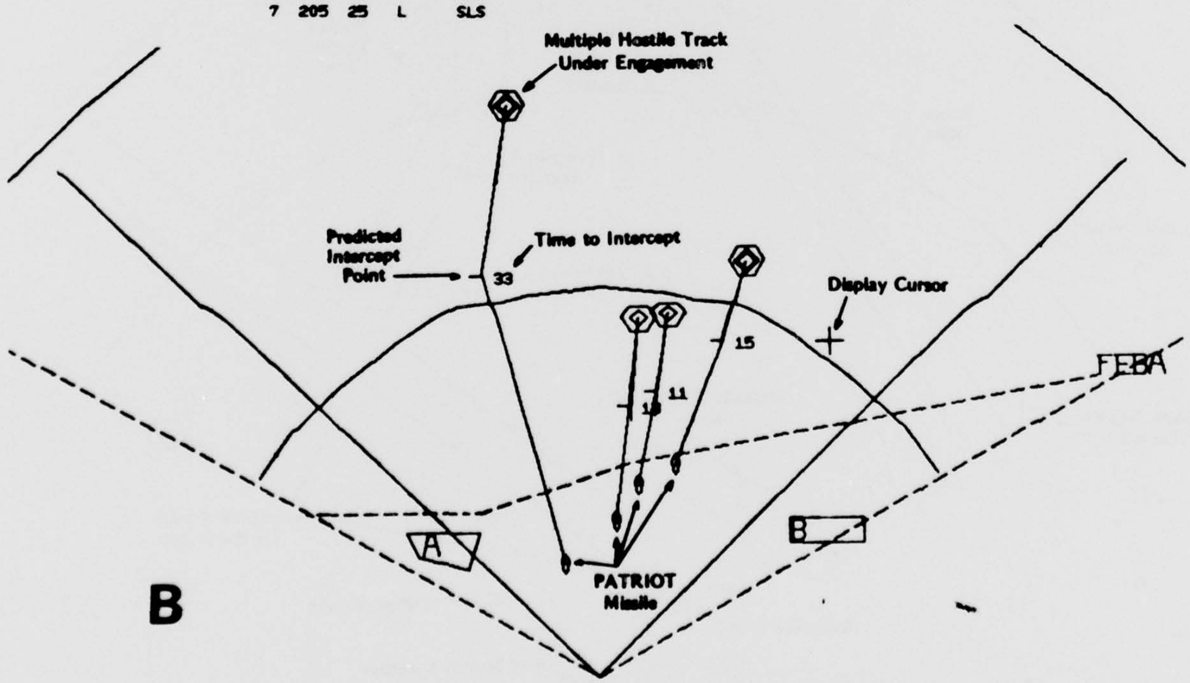


Figure 8. Typical PATRIOT Display



TRK	TLL	TFL	LTH	DA	W/F	- TRK	TTI	WA	WH	W/F	DHDG	DALT	KA
- 14	65	0	H		SLS								
3	105	0	H		SLS								
6	140	20	L		SLS								
7	205	25	L		SLS								



TRK	TLL	TFL	LTH	DA	W/F	- TRK	TTI	WA	WH	W/F	DHDG	DALT	KA
						10	11	X	H	SLS	0	0	
						8	13	X	H	SLS	0	0	
						12	15	X	H	SLS	0	0	
						3	33	X	H	SLS	0	0	

Figure 9. Dynamic Elements of the PATRIOT Display

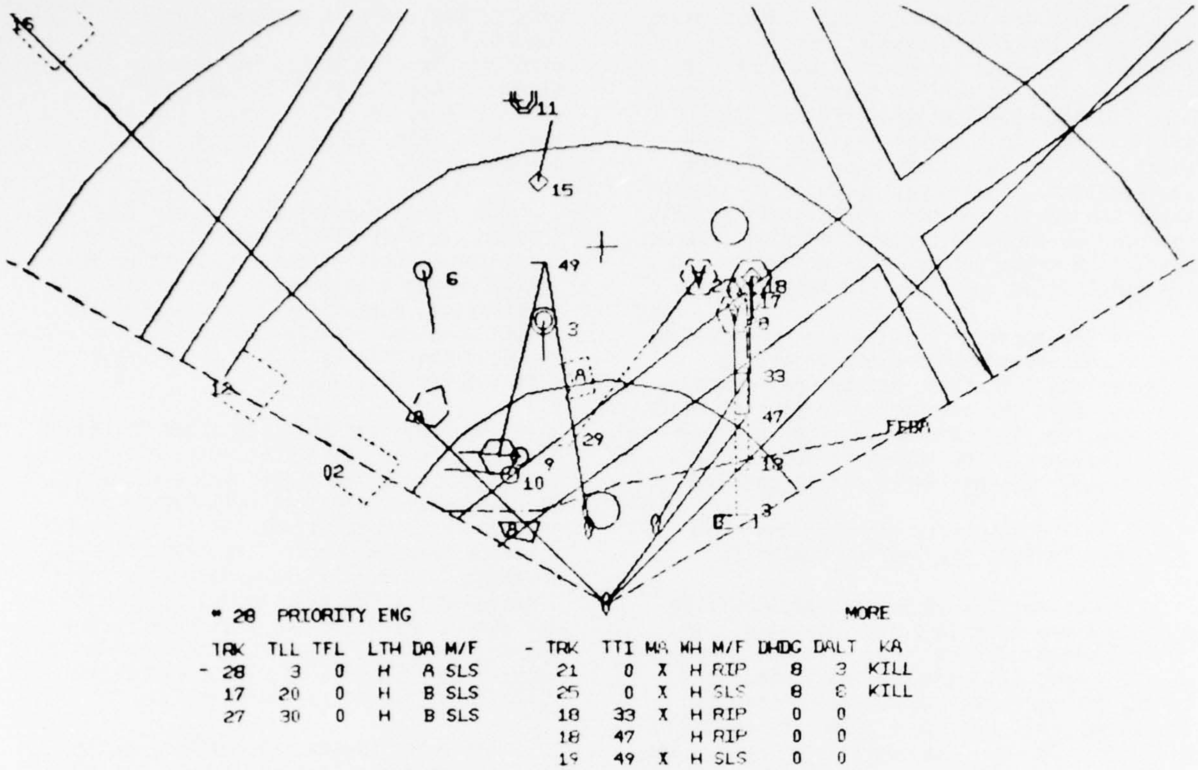
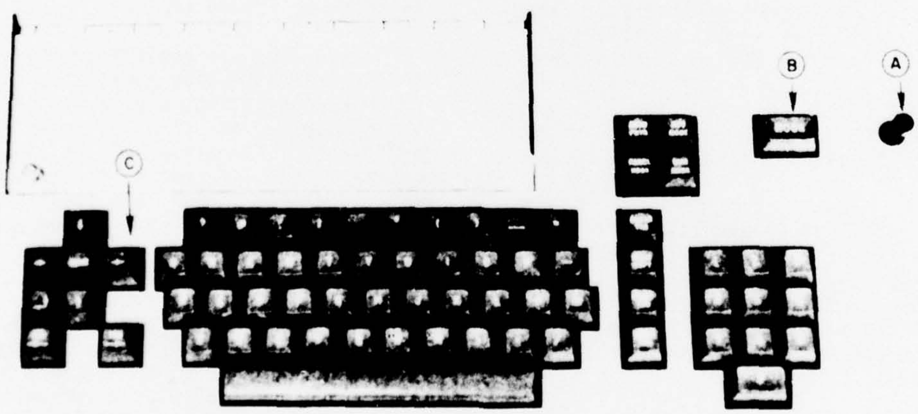


Figure 10. A Typical PATRIOT Display



A. Isometric Joystick

B. Manual Hook Key

C. Tabular Cursor Controls

Figure 11. PATRIOT Display and Control Console Shelf

Targets are identified and classified as they enter the radar-tracking sector, and are displayed as coded symbols. Each target is then subjected to various tests which determine its engagement eligibility and threat eligibility. If a target meets these criteria, further tests determine which asset it threatens. Then a launch-decision process ranks the target for engagement; this process is based on location of the predicted intercept, time urgency to protect an asset, and the initialized operator time requirements.

If the operator initiates an engagement, the weapon-assignment process selects a launcher and a missile, and begins launch action. When the engagement terminates in an interception, the program performs a target-kill assessment; the target is then either "destroyed," or considered for re-engagement.

I will now briefly describe the HEL-simulated PATRIOT Display and Controls.

The operator sees a basic picture like the one shown in Figure 8. This is a Plan Position Indicator (PPI) display which is on at all times. It shows the radar-boundary limits for searching and tracking targets, and range rings used as a guide for target distance. Through the operator's key actions, additional map data are available for display. These data include radar-masking terrain, air corridors, prohibited areas, restricted areas, defended areas, and the forward edge of battle area (FEBA). Dynamic elements shown in Figures 9A and 9B appear and are updated under program control. These elements include target symbol modifiers, track numbers, velocity vectors, defensive-missile symbols, launch-now-intercept lines, target-patch history, and predicted intercept points. The operator has the option of displaying or removing these elements by key action.

Tabular displays appear in an area directly below the PPI display. They consist of an alert-message line and three mutually-exclusive tabular displays: missile inventory, engagement data which is divided into to-be-engaged and engaged tracks and track-amplifying data.

Figure 10 shows a complete rather active display as an air-defense operator would typically see it.

The console contains 108 keys, of which 32 are under program control. Designated keys also contain a lamp which is under program control and which is used to indicate the status of the condition related to that key; i.e., function is active when lamp is on. Since keyboard functions are handled by a subroutine or set of subroutines, it is easy to add, delete, or alter keyboard functions as needed. This increases the simulation's flexibility and permits testing alternate key functions without affecting the remainder of the program. The keys are separated into functional groups on the console panel.

The console operator uses an isometric joystick to control a PPI-display cursor as a pointer to hook targets for further evaluation and/or engagement. The operator's performance, especially in time-critical situations, depends upon his ability to place and hold the display cursor close enough to a target for hooking.

The isometric joystick shown in Figure 11 is a pressure-sensitive stick with analog output. Unlike the other devices, the isometric joystick requires relative cursor positioning, since it returns to the center position when released. The rate of cursor movement is directly proportional to stick displacement. The transformation from digital output to raster units is selected by the experimenter, allowing great freedom in varying the cursor's movement rate as a function of the stick pressure.

The experimenter has complete control over the operator testing through his own monitor display, function keyboard and the teletype. The experimenter begins the test by entering "/SAM" on the teletype. This begins the execution of the simulation program, which causes the computer requests as shown in Figure 12.

Responses are entered on the teletype, and program execution continues. The experimenter's display duplicates the operator's display, and it also shown certain additional information only to the experimenter. This information includes elapsed time, scenario number, and other pertinent system data not displayed to the operator. Using his function keyboard, the experimenter can also "reload" the missile launchers when they are depleted. The experimenter can halt the display at any time, for discussion of critical situations during operator training, or to obtain a hard copy of the situation display shown on the console. Test termination is also controlled by the experimenter through the function keyboard. At termination, the test results are stored by test number.

Specific programs have been developed to assist in analyzing the test. These routines will display data on a CRT for viewing, or make a permanent record on the STATOS printer. Events can be listed chronologically or by track. Other routines summarize the operator's key actions,

target-kill assessments and intercept locations, target-asset penetrations and operator hooking actions. A program has been developed that will replay the scenario and duplicate the operator's actions, so the experimenter can discuss and evaluate these actions with the operator. The playback is also valuable as a performance training aid for the operator.

Test results can be maintained on the disc indefinitely, and they are accessible for analysis at a later date.

Operator Performance Testing:

I will now describe the operator performance testing performed on HEL's PATRIOT Display and Control Simulator.

Since there was no test data available where PATRIOT operator performance could be compared, it was decided to obtain performance measures using the current D&C system design to establish a baseline of performance measures. Once this was done, software modifications were made to the design and tested to determine whether they improved operator performance over the baseline design.

Since time does not permit me to go into an explanation of the PATRIOT display and control features and capabilities, I will describe only a few of the modifications which significantly improved operator performance.

During our testing on the baseline system, we found that operators were having difficulty in performing the following tasks as stated in Figure 14.

To reduce or eliminate the above problems in hopes that operator performance would be significantly improved, the following software changes were made:

a. To improve performance on both detecting air-to-surface missiles (ASMS) and critical alert messages (problems a & e), ASMS which were originally not threat ordered were threat ordered in part; i.e., those ASMS which were targeted within a certain distance of the firing platoon were threat ordered in order to improve the self-defense posture of the firing platoon. Thus, the ASMS which were threat ordered were now put on the To-Be-Engaged section of the tabular display along with other aircraft threats. When one of these targets met a certain criteria, it initiated a blinking priority engagement visual alert message to the operator along with an audible alert. With this change, all the operator had to do was to acknowledge the alert and issue an engage command.

In the baseline system there was no audible alarm provided for critical threat ordered aircraft. At times the operator was not aware of the blinking alert message and he's had to depend strictly on his own surveillance capability to detect an ASM symbol on the PPI display. Once the ASM was detected, he had to use his joystick to manually hook the ASM track before he could issue an engage command. With the changes, the ASM track was automatically hooked when the priority engagement alert message was acknowledged.

b. To eliminate the operator task of moving the tabular cursor back to the first line of the TBE tabular display, all that was needed was a software change to prevent the cursor from moving down to the next line after a sequence hook action was taken by the operator. Apparently, when the sequence hook was designed, the contractor did not remember that the next logical action an operator would take after sequence hooking a track on the To-Be-Engaged display, would be an engage action. Once an engage action was taken, the track on the TBE display moved to the Engaged part of the display and all other tracks on the TBE display were reordered with the track on the first line having the highest priority; however, the tabular cursor was now on the second line and the operator had to move it back to the first line so that he could hook and engage the highest priority target. Remembering to do this task frustrated a number of subjects to a point where they completely refused to use the sequence hook function. I might add that once the change was made, the subjects found that this method of hooking was very effective, especially in times when there were many hostile tracks on the display and they preferred this hooking method over the manual/joystick hooking method.

c. To reduce the unknown identification time, a new tabular display was developed that listed all the hostile criteria for the unknown track. (See Figure 15.) All the operator had to do was count the number of hostile criteria exhibited by the track. If the number equaled or exceeded the TSOP number of criteria for an unknown track to be hostile, the operator designated the track hostile.

d. To eliminate the operator task of remembering to select the Ripple Method of fire on a multiple hostile track, the proper method would be automatically selected by the computer on a hooked target. I'm sure this short description of the problems and the modifications made to correct them leaves a lot of gaps, and if you want a more thorough understanding please feel free to talk to me later. The test results where our modifications showed a significant improvement in

Computer Output	Meaning
Scenario XX	Scenario Number
SAMS XX	SAM Missiles Available
TEST CONSOLE X	Test Console Number
TEST NO XX	Test Number (warns experimenter if number has already been used)
SUBJECT INFORMATION	Subject and Test Data

Figure 12. Computer Output Requesting More Data

1. To evaluate the current PATRIOT Display and Control (D&C) Design for performing air-defense missions in a benign environment.

2. To develop display and control modifications for improving the current display design.

3. To determine the effectiveness of these modifications on air-defense operator performance.

4. To assess the adequacy of an HEL developed Tactical Standing Operating Procedure for PATRIOT.

5. To examine operator performance under different target densitites.

Figure 13. Operator Performance Test Objectives

1. Detecting and engaging air-to-surface missiles within the short time period that these targets could be engaged and intercepted.

2. Remembering to move the tabular display cursor back to the first line of the To-Be-Engaged Tabular display after hooking a target on the first line.

3. Comparing TSOP Hostile criteria with an unknown track's paremeters for the purpose of declaring an unknown track as hostile.

4. Remembering to select Ripple Method of Fire on a multiple hostile track.

5. Detecting and rapidly responding to visual alert messages-even critical alert message.

Figure 14. Observed Problems on Baseline System

operator/machine/mission performance are shown in Figure 16. A total of 16 military air defense personnel having varying amounts of operator experience of the HAWK System served as subjects for this PATRIOT test. Based on our test results, we submitted a total of 10 recommendations to the PATRIOT PMO.

Upon completion of our formal testing and preparation of the report (HEL TM 15-77), it became rather obvious that our PATRIOT simulator could be used as a training device to provide some advance training of government personnel having responsibilities for DT/OT planning/testing and development of training devices. To date, over 30 personnel from the PATRIOT PMO, OTEA, TRADOC, TECOM, and AMSAA have taken our informal indoctrination training on the HEL Display and Control subsystem simulator.

The benefits which can be realized from this effort are shown in Figure 17.

Finally, in regards to our future tests planned for the PATRIOT simulators. The topics to be studied are shown in Figure 18.

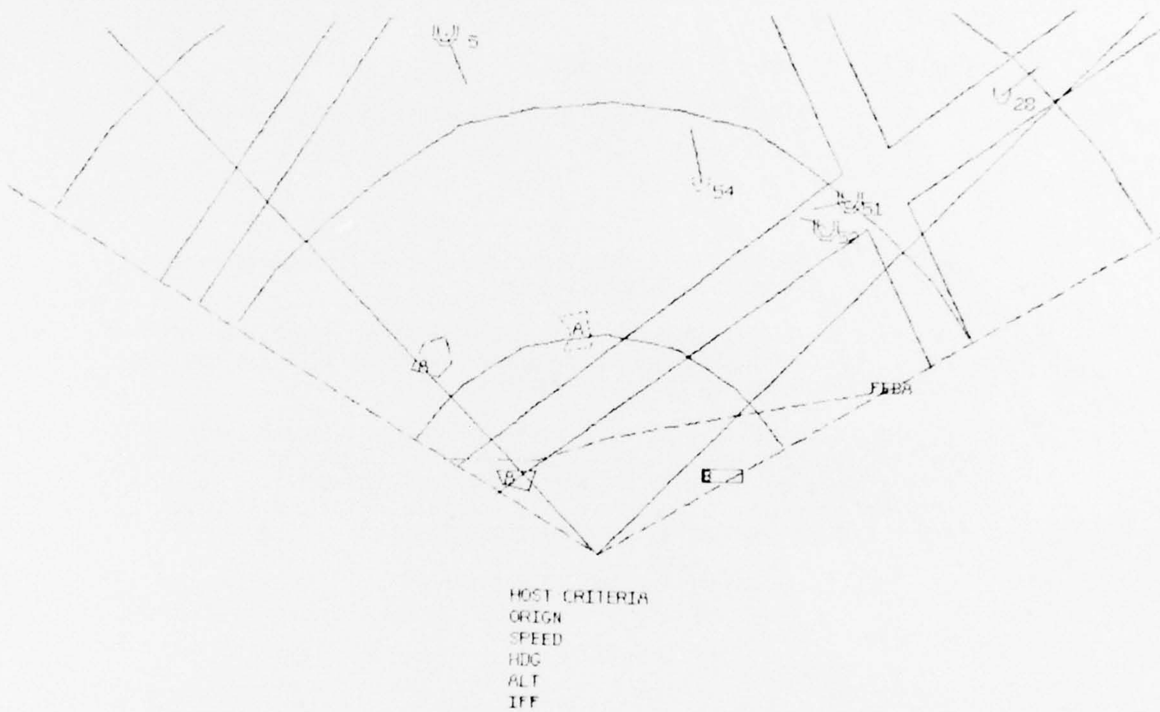


Figure 15. New Tabular Display for Identifying Unknown Tracks

Dependent Variables	Baseline System	Modified System
Unknown Track ID Time *(sec)	50.6	33.4
Priority Alert to Acknowledge Time **(sec)	5.0	2.5
Priority Alert to Engage Time *(sec)	6.0	4.2
Mean Time to engage FP directed ASMS*	15.0	10.0

*Significant at .05 confidence level using Tukey's Test of difference between the means.

**Significant at .01 confidence level.

Figure 16. PATRIOT Display and Control Evaluation Test Results

1. Reduces the need and costs of conducting special human engineering field tests on the actual system equipment.

2. Provides visibility on human engineering problems existent in the current system design. Detecting and correcting these problems now is less costly than when the system is fielded.

3. Provides a technical baptism to personnel in the test and training communities whereby they are better prepared for structuring their respective tests and defining their training requirements; i.e., when you know how a system is to perform, you are in a better position to prepare a test for measuring the required performance.

Figure 17. Training Benefits

1. Display study on operator capability in an ECM environment.

2. Task/workload divisions using two Display and Control consoles.

Figure 18. Future Tests Planned

ABOUT THE AUTHORS

MS. PATRICIA J. WILLIAMS has been employed at the Human Engineering Laboratory at Aberdeen Proving Ground, Maryland as an Engineering Psychologist since 1974. Publications include "Air Evaluation of Operator Performance on the PATRIOT Display and Control Console" and "Target Tagging Accuracy as a Function of Cursor Shape and Size." She received a B.A. degree in psychology from Towson State College in Baltimore.

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MR. JAMES W. GOMBASH has been employed at the Human Engineering Laboratory at Aberdeen Proving Ground, Maryland as an Engineering Psychologist since 1976. Prior to that he was employed as an Engineering Technician at the U.S. Consumer Product Safety Commission in Bethesda, Maryland. Publications include "An Evaluation of Operator Performance on the PATRIOT Display and Control Console"and "Target Tagging Accuracy as a Function of Cursor Shape and Size." He received a B.S. degree in psychology from the University of Maryland.

TOW MISSILE SIGHT VIDEO TRAINING SYSTEM

NORMAN GUTLOVE and JOHN STANFIELD

Imaging Systems Division
Federal Systems Group
Fairchild Camera & Instrument Corp.

INTRODUCTION

Maintaining a high first round weapon system kill probability through effective gunner training has become increasingly important with escalating cost per round. Recent advances in the state-of-the-art in video cameras employing all solid-state, charge-coupled device (CCD) technology have prompted a reevaluation of current training techniques and devices. This paper discusses the application of this new technology in a training environment.

The Fairchild TOW Missile Sight Video Camera System (TMSVCS) provides a capability for real-time monitoring and assessment of gunnery performance and immediate post-mission playback and analysis of gunner aim point during live or simulated firings of the TOW Weapon System.

In this helicopter application, the gunner, located in the front seat of the AH–IS TOW COBRA, utilizes a stabilized Telescopic Sight Unit (TSU) with which he can detect and accurately track a target. As an aid to gunner training, and for effectiveness evaluation, provisions for a 16mm film gun camera form a part of the TSU. Training benefits of this film record are minimal because of the several day delay between exposure and screening of the film due to film processing requirements. Additionally, light level variations limit the usefulness of film cameras. Another training aid, the Gunner Accuracy Control Panel (GACP) displays azimuth and elevation gunner errors to the instructor-pilot (IP) in the second seat of the helicopter, but this system is usable only with specially conditioned targets.

The TMSVCS overcomes these shortcomings by providing the instructor-pilot with a real-time image of gunner's field-of-view, including the TSU reticle, on a high-brightness video monitor. In a training exercise, the IP can observe and verbally correct the way in which the gunner sights on the target and maintains position from initial acquisition to impact. Tracking errors and jitter in azimuth or elevation can be observed dynamically and corrected instantaneously.

For immediate detailed review of gunner performance upon return to base, the on-board video tape recorder (VTR) can be utilized. The video tape cassette, removed upon landing, can be replayed on a VTR and displayed on a video monitor for performance review, assessment and correction; this procedure can take place much more rapidly than in the case of 16mm film and therefore represents a significant training aid improvement for the IP and student. Relative advantages of the TMSVCS are summarized in Table 1.

TABLE 1.

VIDEO TRAINING BENEFITS

- No Target Conditioning Required
- Real Time IP Observation/Verbal Queing
- Immediate VTR Playback on Landing
- 40 Simulated Firings on a Single Cassette
- Reusable Tape Cuts Cost
- Short Term Record to Demonstrate Improvements
- Modular Growth
- Operational Value
  - RECCE
  - Damage Assessment
  - Landing Aid

TMSVCS CAMERA SYSTEM DESIGN

The Fairchild TMSVCS is made possible by the recent availability of small, rugged low light level TV cameras, high brightness monitors, and video tape recorders ruggedized for use in the helicopter environment. The smallest, most rugged and reliable TV cameras available employ a solid-state imaging device rather than a vidicon tube. Fairchild has developed solid-state charge-coupled device (CCD) area imaging arrays and cameras which are ideally suited to this requirement. Operation at the low-light levels available from the TSU beam splitter is possible because of the superior CCD sensitivity.

The CCD camera is mounted in a special bracket which maintains the same TSU interface as the previous film camera. The dynamic range and AGC characteristics of the CCD camera permit effective operation over a wide range of scene brightness without exposure control. This provides a state-of-the-art system with high reliability at a modest cost.

The TMSVCS camera is depicted in Figure 1. The CCD camera output feeds both a video tape recorder and high brightness monitor. TMSVCS power is switched manually via a remote switching and control panel conveniently located for operation by the IP. Automatic tape recorder shut-off is provided with a manual override as a tape saving feature and assures that the recorder is not inadvertently left in a RECORD mode for extended periods.

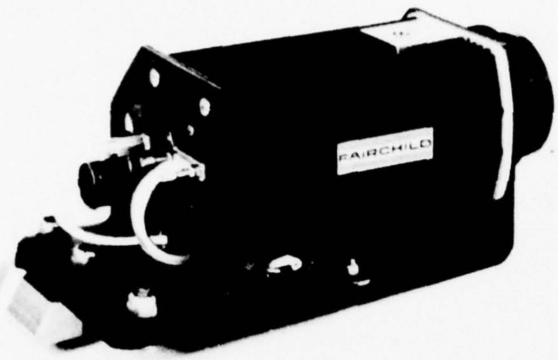

Figure 1. TMSVCS Camera

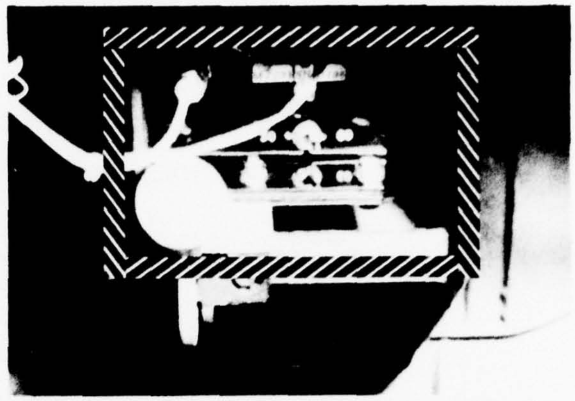

Figure 2. Installation of TMSVCS Camera in the TSU

The CCD television camera uses a modified positioning ring and retaining shoe similar to those used for the film camera body. This assures that the mechanical and optical interface is maintained without modification to the TSU. Locating the small CCD format (7.2 mm diagonal) in the 16mm film image plane (12.6mm diagonal) reduces the displayed field of view to 57%. This provides improved target resolution and image magnification and enhances the instructor's ability to assess gunner accuracy at the projected time of target intercept.

Figure 2 shows the installation of the TMSVCS camera in the TSU. The small size of the camera is evident from the photograph, and clearly indicates that the camera does not interfere with the gunner during TOW System operation.

A performance specification for the CCD video camera is given in Table 2.

Higher resolution and/or a greater field of view can be provided with a full TV resolution CCD camera as requirements dictate. Specifications for the full resolution CCD camera are given in Table 3.

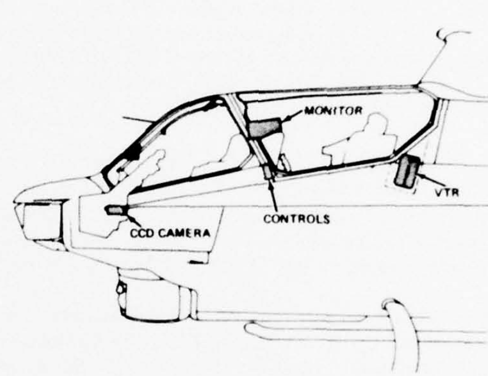

Figure 3. TMSVCS Installed in AH-1S Helicopter

VIDEO TAPE RECORDER AND MONITOR INSTALLATION

A High-Brightness Video Monitor is mounted on the top of the gunners seatback for viewing by the instructor pilot (Figure 3). The small size of the display serves to minimize obstruction of the IP's forward view in this location, and the increased visibility offered by use of the television camera more than compensates for the area blocked by the monitor. The video tape recorder and system power supplies also depicted in Figure 3 are located in the space immediately behind the pilot's seat.

RESULTS AND CONCLUSIONS

The last four figures, photographed from the television monitor, depict actual scenes viewed through the TSU/CCD camera system and illustrate the performance capability of the TMSVCS. In Figure 4 a tank located at a distance of 2,800 meters is shown at 13 x magnification (the high magnification setting of the TSU). To the right in the figure, a TOW missile approaching the target is barely discernible. A few hundredths of a second later, the missile strikes the target and approximately 70 milliseconds after missile impact the scene appears as shown in Figure 5. The two magnifications available with the TOW Sight are clearly illustrated in Figures 6 and 7 where the same helicopter is shown in the air at a range of 2,500 meters at both magnifications. All four pictures (Figures 4 through 7) were photographed at approximately 9:00 AM under overcast sky conditions.

Other closely related applications for the same basic Fairchild TMSVCS components include Aircraft Electronic Gunsight Cameras and potential use in any weapon systems employing optical sights or as visual confirming sensors for other types of scoring systems. On-board TV cameras, displays, and recorders should find increased application to real-time reconnaissance and damage assessment systems, as well as helicopter cockpit display recording. Field deployment will continue to disclose other applications of the TMSVCS and further add to a growing list of benefits of video systems in the institutional and field unit operational environments.

TABLE 2.

TMSVCS CAMERA SPECIFICATION

SENSOR	FAIRCHILD CCD ARRAY
SPECTRAL RESPONSE	0.45–1.06 MICROMETER
OPTICS	TSU COMPATIBLE; FIXED AND VARIABLE FOCAL LENGTH OPTICS AVAILABLE
LENS MOUNT	STANDARD "C" MOUNT
SENSITIVITY (NOTE 1)	SCENE BRIGHTNESS 0.0125 FOOT LAMBERTS; SENSOR ILLUMINATION 0.00125 FOOT CANDLES
ELECTRONIC AGC	>80:1 RANGE
GEOMETRIC LINEARITY	NO CAMERA DISTORTION
FRAME RATE	30 FRAMES PER SECOND
FORMAT	244 LINES; 190 PICTURE ELEMENTS PER LINE
SYNCHRONIZATION	2:1 STANDARD INTERLACE
VIDEO OUTPUT	1 VOLT PEAK–TO–PEAK COMPOSITE VIDEO (RS 170 COMPATIBLE)
VIDEO LINE OUTPUT	UP TO 500 FEET; 75 OHM
POWER	28±4 VOLT DC; 4 WATTS
CAMERA SIZE	2–1/2" W, 2" H, 3–3/4" L

NOTE: HIGHLIGHT SCENE ILLUMINATION WITH 2854°K SOURCE (TUNGSTEN) USING f/1.4 LENS FOR A S/N RATIO OF UNITY.

TABLE 3.

PRELIMINARY SPECIFICATIONS
FAIRCHILD MV-301 CCD-TV CAMERA

SENSOR	FAIRCHILD CCD 488 X 380 ARRAY
PERFORMANCE	
FRAME	488 LINES, 380 PICTURE ELEMENTS/LINE
SENSITIVITY	5×10^{-3} FT LAMBERTS SCENE BRIGHTNESS*
	5×10^{-4} FT CANDLES SENSOR ILLUMINATION
SPECTRAL RESPONSE	0.45 TO 1.06 MICROMETER
GEOMETRIC LINEARITY	NO CAMERA DISTORTION. SYSTEM PERFORMANCE IS LIMITED BY OPTICS AND DISPLAY
OPERATING CHARACTERISTICS	
FRAME RATE	30 FRAMES/SEC
LINE RATE	15750 LINES/SEC
SYNC	2:1 STANDARD INTERLACE
VIDEO OUTPUT	1V P-P COMPOSITE VIDEO (RS170)
VIDEO LINE OUTPUT	500 FT, 75 OHM
AGC, ELECTRONIC	$>$ 80:1 RANGE
ALC, f1.4 SPOT-IRIS LENS	7×10^4 RANGE
POWER	
CAMERA	±12VDC, 5 WATTS
AC ADAPTER	115V, 50-400 Hz
PHYSICAL DATA	
CAMERA SIZE	2-5/8" DIAMETER X 5-1/4" LONG
WEIGHT	1 LB.
OPTICS	STANDARD "C" MOUNT LENS

*HIGHLIGHT SCENE ILLUMINATION WITH 2854°K SOURCE (TUNGSTEN) USING f1.4 LENS FOR A S/N RATIO OF UNITY.

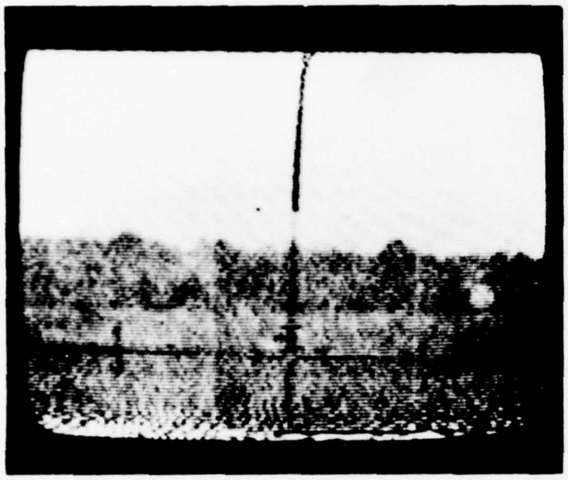

Figure 4. Tank Target: 2800 M; 13 x Magnification

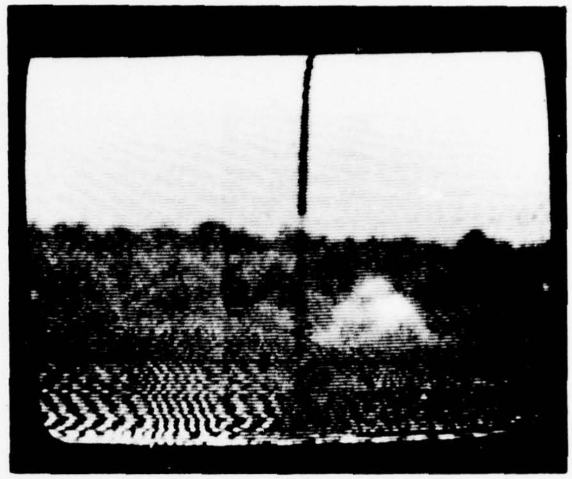

Figure 5. Same Target as Figure 4; Direct Hit

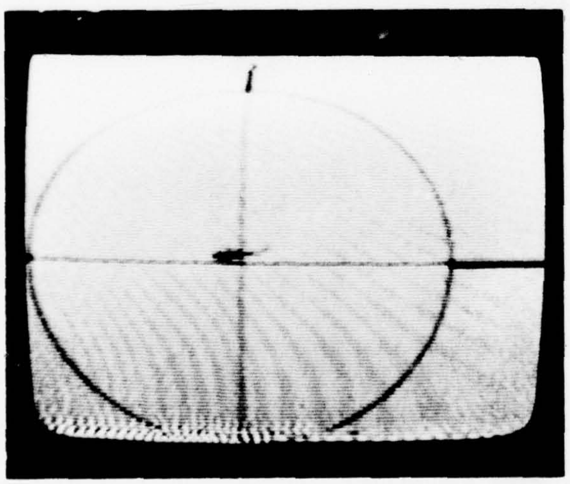

Figure 6. Huey Helicopter: 2500 M; 2 x Magnification

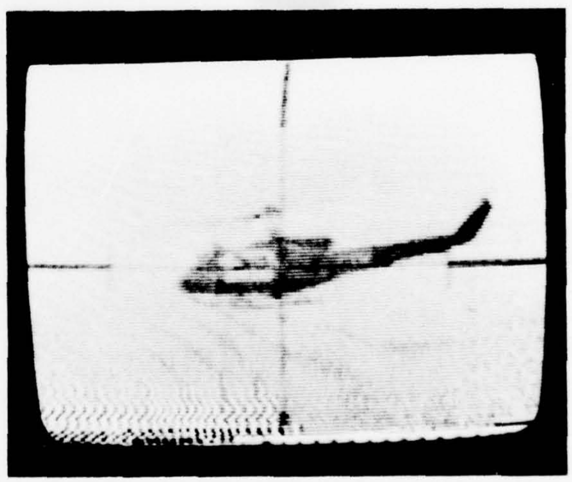

Figure 7. Same Target as Figure 6; 13 x Magnification

ABOUT THE AUTHORS

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DOWNTIME WASTES THE RESOURCE

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Director of Logistics
Link Division
The Singer Company

SUMMARY

This paper presents an overview of Logistics Support problems in Simulation Programs and discusses the impact of Design to Cost and Life Cycle Costs in the Logistics discipline.

DOWNTIME WASTES THE RESOURCE

Logistics - No Longer a "Tail-end Charlie"

The Logistics element of industry has been referred to, in the words of the Now Generation, as "the Pits." Logistics personnel have historically been:

- the last to receive the word
- the last to know about changes
- the last to have anything to do with the hardware or the software

and the first — to feel the wrath of the customer when something goes wrong with the equipment.

Those days are ending. Logistics Support can no longer be a "Tail-end Charlie." Logistics is coming of age.

Design To Cost (DTC) and Life Cycle Costing (LCC), given "lip service" by buyer and seller alike for many years, are now formidable tools and definitive requirements on many of the more recent Government contracts. LCC virtually catapults Logistics from the background to the forefront of a simulation program and for its duration.

LCC may serve to wake up industry and the military buyer alike. Industry, from the standpoint that a very significant checkpoint, namely Logistics, will now actively influence the design and manufacture of simulation equipment, with the specific intent of ensuring that the equipment can be supported in the field. The military customer, in that if he indeed institutes and follows LCC guidelines, he can literally prevent the downstream expenditure of millions of dollars and receive far better, more reliable and supportable equipment.

Logistics Can Make The Difference

Proper Logistics planning and implementation of that plan can make the difference in whether the simulator is a resource asset or a liability.

With increasing concern for fuel reserves and a national, hopefully world-wide, effort to conserve natural resources, it may well be that the simulator building will become tomorrow's flight line. The simulator user will require and demand maximum equipment availability.

To ensure maximum availability, the support pipeline must be clean and smooth flowing.

Most industrial companies recognize the pyramidal costs that *changes and delays cause on their own products.* By this I mean: change a 75-cent resistor in Cabinet A and the costs multiply for drawing changes, publications, provisioning lists, spare parts, and field service bulletins.

Similarly costs pyramid for the simulator user when unscheduled downtime occurs. Figure 1 illustrates the point.

With the simulator down, maintenance personnel, either organic or contractor, perhaps both, enter the cost picture along with the spare parts requirements and associated administrative costs.

In the meantime, instructors are idle and the training schedules deteriorate. The most serious problem lies with the students - for with downtime, schedules must be altered incurring costs for administration, housing, travel arrangement, base and per diem pay. Availability or reassignment billets must be reshuffled to meet the altered training schedule. All of this is backed up with more students arriving or enroute to commence training.

Unscheduled downtime of the simulator is a major headache to the training command.

Three key factors are necessary to maintain the simulator as a viable substitute for the operational equipment:

(1) Device must be reliable and maintainable. The sophistication of today's training devices requires industry to re-evaluate the methods used by the customer in repairing the device. Built in Test (BIT) and Built in Test Equipment (BITE) procedures are becoming essential for organic maintenance personnel to keep the equipment on the line.

(2) Data must be fully representative of the hardware. Configuration Control, of both hardware and software, must

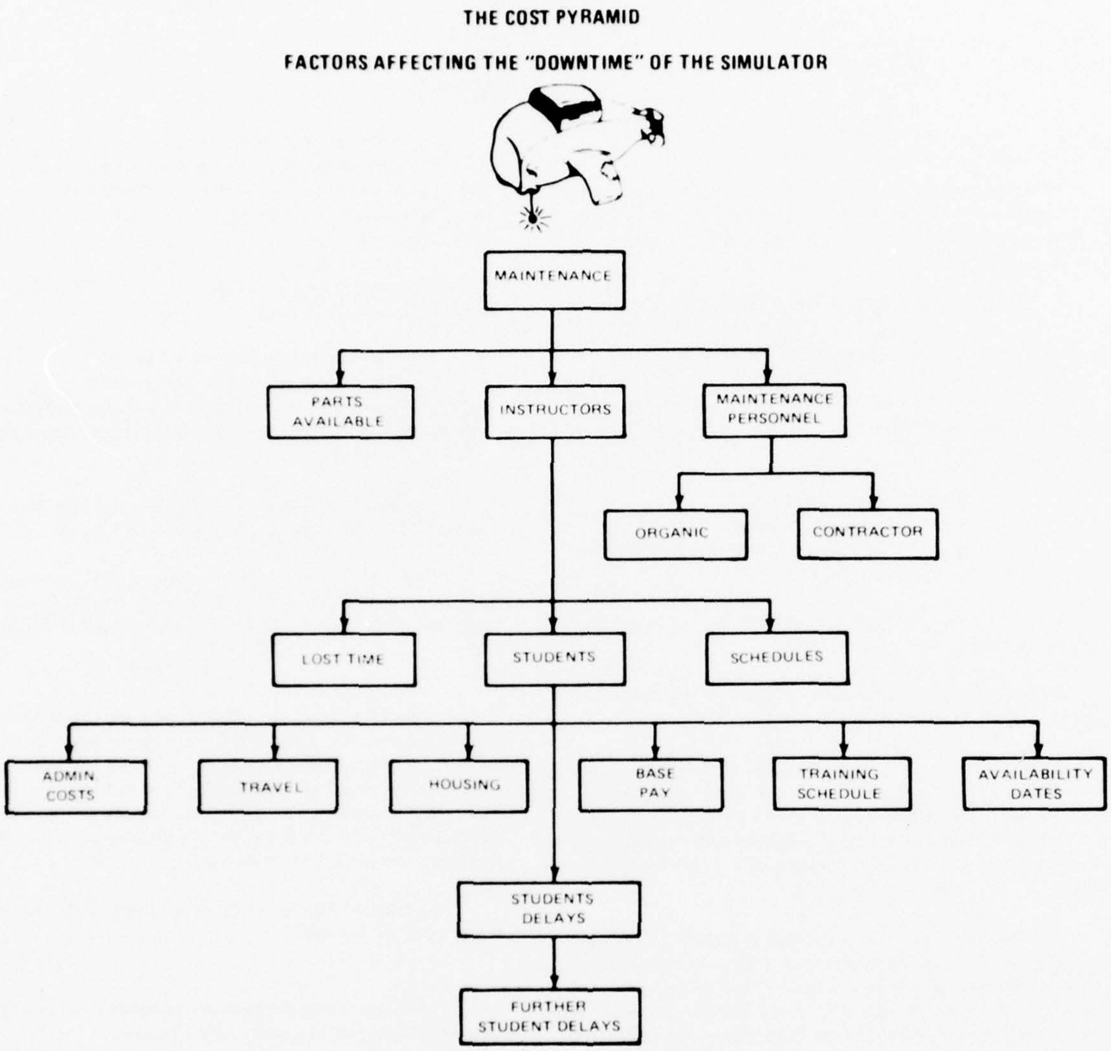

Figure 1. Cost Pyramid

be more rigorously applied and observed by the manufacturer. Likewise, changes made in the field must be carefully documented and appropriate changes made to all of the software.

(3) Spares. Without the proper spare part, of the correct configuration, available and ready for use on-site, Downtime Prevention literally goes "down the tube."

The Logistics Support Team, on the job from program inception through design and manufacturing, and following the equipment to the installation site, can ensure that the Logistics plan is properly implemented, monitored, and carried to a successful conclusion. The Logistics Support Team, fully supported by progressive management, will ensure that the equipment is reliable and maintainable, data and hardware are configured properly, and spares are available at the right time and at the proper site or depot.

The Logistics Support Team, properly trained and motivated, can make the difference.

New Factors In Logistics

As I mentioned in my opening statements, DTC and LCC introduce new factors in the Logistics discipline which will have a profound impact on the methods used to develop a simulator.

It is not my purpose today to expound on the good or bad aspects of the LCC philosophy - except to alert industry and government representatives alike that LCC may well require changes in the modus operandi.

The goal of LCC is to create an optimum system or equipment that will meet the designated specification and that is most cost effective over its planned life cycle.

A continuous dialogue must be established and maintained between designer and logistician as an inherent part of the system development.

This type of relationship will maximize possibilities for early identification of problems, thus forcing design-versus-support trade-off decisions before the design is finalized. Obviously, design is paramount to the cost of ownership. The current Logistics Support Cost (LSC) model supplied by the government to contractors will both assist them in the design process and provide a relative measure of ownership costs.

A new design concept may have to be aborted occasionally in light of the support requirements on a program since, in the trade-off studies, requirements for increased inventory management and new or modified support equipment could very well offset the gains resulting from the new design.

The cost drivers are inventory and maintenance manpower costs. Anything that can be done to a design to reduce the range and depth of inventory that must be carried as spare or repair parts or that reduces the time required for preventive or corrective maintenance will reduce the cost of ownership to the user. Whether it is an overall benefit to LCC is the subject of trade-offs with the cost of acquisition.

A simplified, but basically true, example illustrates the point:

If you were to create a new dash number for a PC Master Controller Board, it would cost the user approximately $4,000 over a 15-year life cycle. Add one new component to that PCB and you have doubled that cost. The PCB is also an item of supply at each base for remove and replace, so add about $5,000 more. If it is also repairable at the base, add $10,000 more. A simple dash number change and adding one new component, and you have caused user expenditures in excess of $23,000.

Let's assume that same PCB has a failure rate of once every four years. That means we can expect three failures during the 15-year life cycle. The predicted average MTTR is approximately one hour.

Each failure directly affects at least three people: the student pilot, the instructor, and the maintenance man. Manhour expenditures also occur in obtaining the replacement PCB, documenting the failure, and repairing the failed board.

The total cost of one failure every four years on PCB's located at 6 bases (assuming 6 simulators and 12 master boards per simulator) equates to approximately 700 manhours. At $20/hour, the cost is approximately $14,000.

From a cost of ownership standpoint we have committed over $37,000, and have not even considered the cost of spare/repair parts, support equipment, or training. Those $37,000 are trade-off dollars. Can $37,000 be spent on design to reduce the cost of ownership by $37,000? If the answer is yes, then LCC is being optimized.

Numerous considerations must be exercised during the design process. Each affects the cost of ownership for the user (customer). The overall ranking of these considerations can range from significant to minimal. Here are a few examples:

(1) New design versus old - new national stock numbers and inventory management are expensive. New design impacts all LSC elements.

(2) Repairable versus throwaway - throwaway may be cost-effective for operational weapon systems, but it seldom is so in the simulation world.

(3) Mean-time-between-failures (MTBF) and Mean-time-to-repair (MTTR) - significant since they directly influence the number of people required to support the product. Personnel costs in the services have greatly increased, even though the number of personnel is less. Indirectly, MTBF and MTTR influence the cost of spare/repair parts, publications, support equipment, training, and even facilities. However, over-design can be just as bad as under-design.

(4) BIT/BITE versus AGE (test and support equipment) BIT/BITE should be maximized for fault isolation and improved availability. AGE is expensive when considering multiple procurements at scattered bases. BIT/BITE also improves MTTR through more rapid and detailed fault isolation.

(5) Level of repair - the cost of repair at the depot level vs. organizational and intermediate levels varies with the complexity of the equipment and the repair parts which must be stocked at each base along with any peculiar test/support equipment.

Design can no longer be directed toward just meeting the specification requirements. Considerations must be given to the user's cost of ownership over the life cycle of the design.

I have presented a very broad overview of some of the factors of the DTC and LCC systems. Seminars are being conducted all over the nation covering these subjects and I might suggest that industry attend and support them.

For the contractor, I suggest the following areas may have some impact on operations:

(1) New and revised designs will have to be approved by Logistics.

(2) Improved engineering knowledge for Logistics personnel will be essential.

(3) Cost/pricing structures may have to be revised in order to correlate Logistics Support Costs.

(4) Technical and Cost Proposals may have to reflect very clearly how the contractor truly believes his equipment will perform.

(5) RIW (Reliability Incentive Warranties) may increase the liability of the contractor enormously - if the equipment design is not adequate.

(6) Organizational structures may have to be modified.

"Downtime Prevention" Starts With the Buyer

"Downtime Prevention" should become the "Cost Driver" in a simulation program. Downtime Prevention is the buyer's obligation as much as it is the seller's. I would like to briefly discuss several areas of potential improvement that could be instituted by the buyer and which may result in the savings of many dollars not only in the initial procurement, but during the life of the equipment.

(1) Application of MIL Specs - RFQ's and resultant contracts still contain "specs by the pound." Many of them are not even particularly relevant to the procurement of simulation equipment. I suspect many specifications are included in the RFQ package only because they were included in the preceding RFQ for another simulation device - and what was good for one must be good for another. I suggest a hard look at the spec requirements by the procuring agency and the operations people before issuing the RFQ.

(2) Commercial Components - The overall Logistics problem could be made substantially simpler and less costly by the increased use of proven, reliable commercial components and equipment. Test equipment is one specific area where the use of commercial off-the-shelf equipment should be further explored by the military. Recently, at an Army seminar, we witnessed an example of two pieces of test equipment side by side - one a commercial unit - the other militarized with all the accompanying specifications. Both pieces performed the same job - however, the military version, after being ruggedized, fungus proofed, waterproofed, drop tested, etc. - could no longer fit through a hatch in an Army tank where it was required to be used.

(3) Spares - The identification and selection of spare parts is a tedious, time consuming and costly task. The spares provisioning conference also performs a service to the customer of which he may not be aware. It serves to point out the potentially weak areas in the equipment design.

However, if we are to keep the simulator on the line, spares must be determined, selected, procured and the contract negotiated in a more timely fashion.

If more commercial, off-the-shelf type components were used in simulators, "downtime" could be improved by permitting military personnel to procure components at the local Radio Shack outlet.

The Logistics Support Group Can Do More -

From the contractor's side of the Downtime Prevention problem, I would suggest that the Logistics Support Group can do more if one or more of the following were selectively reviewed in-house:

(1) Organization Structure - It is very probable that many companies represented here today have created organization structures in order to do business with the Government. Logistics groupings may have been one of these organizations. I suggest that a review of your organizational structure may result in a more homogenous grouping which will better serve your company, as well as the customer, and provide a better means of support for the equipment.

(2) Personnel - A well known commercial company uses the slogan, "The Quality Goes In Before the Name Goes On". We might well keep that in mind when selecting personnel for the Logistics Support Team. Maximum availability of the simulator may require upgrading and retraining of Logistics personnel - both in management and labor categories. Make the Logistics organization one that people will want to join.

(3) Design Approach - With the introduction of LCC requirements, it becomes necessary for the Logistics organization to have design approval. I would suggest that this requirement be fully explained to all personnel active on a given program and then rigidly enforced.

(4) Computerization - Many of the Logistics functions such as provisioning, spares, AGE, Reliability and Maintainability are heavily concerned with statistics and/or numerical and alpha listings. The manual inputting and correlating of Logistics data is not only time consuming, but costly.

If you have not already done so, I would strongly urge you to apply some of your best software people to the task of computerizing the Logistics data tasks. A couple of good programming people in your Logistics group could conceivably save you and your customers a considerable sum of money.

(5) Consult Your Customer - Insist on your Logistics team going to the field. Interview the user of your equipment. Find out what support data he really uses to maintain the equipment. See which documents, such as maintenance and operation manuals, have dust on them - and find out why. In this manner, you can help the customer and yourselves and perphaps reduce some of the unnecessary requirements of simulator contracts.

Summary

To summarize my remarks, may I simply state that if simulation is going to fully answer the resource conservation problem, Logistics must and will play a much greater and more important role in the overall procurement process.

Logistics can no longer be a "Tail-end Charlie", but must be fully involved and cognizant of the front-end planning and design of simulation devices and must continue through the entire program to monitor and implement the action to prevent downtime from wasting the resource.

DTC and LCC can be useful resources to both buyer and seller if they are administered uniformly and properly. If allowed to proceed in an uncontrolled, free-running state, they will serve no one, but will develop another "cultism" to swell the administrative tide.

Industry should respond to the need for more reliable and maintainable equipment by developing a sound Logistics organization capable of implementing and following through on good, common sense, economical Logistics plans.

The military buyer must be amenable to buying less than the "gold brick." I strongly urge that the wholesale proliferation of specifications used on government contracts should be sharply curbed.

The use of established, reliable, commercial off-the-shelf products should be encouraged. Methods should be developed by the military user to enable procurement of commerical components in local areas.

Simulation devices are important tools to our nation's defense - not only as a method of conserving our national resources, but as a viable substitute in keeping our armed forces "mission ready."

Logistics can make the difference.

ABOUT THE AUTHOR

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QUALITY ASSURANCE AND REVALIDATION: THE CHALLENGE TO MANAGEMENT

K. LARRABEE
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INTRODUCTION

The training device Quality Assurance and Revalidation Program (QA&R) as operated by the United States Navy represents a unique approach to assuring adequate training device performance. This program applies to training equipment ranging from flight and weapon systems simulators to aviation physiological training systems such as ejection seat trainers and altitude low-pressure chambers.

The Quality Assurance and Revalidation program had its beginnings in 1967 when Admiral Moorer, then Commander-In-Chief of the Atlantic Fleet, had training device effectiveness reviewed to determine just how well training devices were fulfilling the Navy's needs. The result of these original and early inspections was an internally operated, integrity inspection system. Later, in 1969, Chief of Naval Operations (CNO) issued the first instruction implementing a Quality Assurance and Revalidation Program. The latest Chief of Naval Operations Instruction defines Quality Assurance as a "planned and systematic pattern of actions necessary to provide adequate confidence that training devices will continue to perform satisfactorily."

As pointed out by the theme of this conference "Resource Conservation Through Simulation," the simulation of weapons and flight systems can provide significant reductions in the cost of training and the maintenance of needed operational skills. However, without some guarantee that training systems and simulators provide accurate and up-to-date training, there exists a real danger of providing inadequate, negative, or dangerous training through improperly operating simulators and trainers. By pursuing an active and vigorous Quality Assurance and Revalidation Program throughout the Navy, the Chief of Naval Operations provides adequate safeguards so that management will be informed should training device or simulator capability fall below established minimums.

OBJECTIVES

The primary objective of the QA&R program is to provide confidence in a device's performance and its ability to provide adequate training within a given environment. To accomplish this primary objective, several major elements are necessary.

These major elements are:

a. Ensure that training devices operate within prescribed technical and operational acceptance criteria and meet the training mission requirements of the training agent.

b. Improve safety in operations.

c. Provide feedback data for continual improvement of the logistic support program.

d. Improve maintenance and support techniques and procedures.

e. Uphold the material reliability and integrity of training devices.

f. Forecast requirements for overhaul and/or modernization.

g. Maintain a continuous training device status record.

h. Identify action to correct device deficiencies.

METHODS

The Chief of Naval Operations has designated Commander-in-Chief Atlantic Fleet, Commander-in-Chief Pacific Fleet, Chief of Naval Reserves, Chief of Bureau of Medicine, and Chief of Naval Education and Training as training agents and, as such, has directed them to participate in the Quality Assurance and Revalidation Program. The Chief of Naval Education and Training was designated as overall program coordinator. Participation of the Marine Corps is directed by the Commandant of the Marine Corps. Responsibility of the training agents with regard to the QA&R program may be delegated as appropriate, but not below the third echelon level of command.

At the appropriate level of command, a qualified officer is designated as senior inspector for a particular device inspection. Since simulation techniques employ a wide range of technologies, a technical advisor is provided by a CNET field activity to assist the senior inspector during the QA&R review. During the inspection of the training device, the senior inspector coordinates the user's evaluation of the training system by observing the device in operation in a fully manned situation after which both user and operator personnel are debriefed for comments concerning operation, utilization, and any required product improvement. The technical advisor provides inspections of trainer systems, computers, environmental systems, and logistics support.

Following the conclusion of the inspection all participants are debriefed as to the findings, and action items are delineated for assignment to various commands. A comprehensive report of the findings and recommended actions is prepared by the senior inspector and the technical advisor for submission to the training agent.

THE REPORT

The QA&R report resulting from a device inspection is the action document of the program. The report not only contains all findings of the QA&R inspection team, but it contains action item assignments made by the team to supporting activities for resolution of problems found during the inspection. The body of the report contains five major categories, which are:

a. Activity Evaluation: The activity evaluation portion of the report consists of observations noted by an actual crew test of the training device in operational conditions. Discrepancies are noted from an operational/utilization and operator/instructor standpoint.

It is during this portion of the QA&R that the senior inspector and all the device using activities evaluate the trainer for its ability to provide useful training in the appropriate realm. In the case of flight and weapons simulators, this portion of the report provides a review of the device capability to replicate the real world in both form and function.

b. Logistic Support: During the logistic support review, all major elements of maintenance support are investigated. Included are the training device documentation systems such as handbooks, schematics, and parts lists. Also, since most major training devices and simulators now use digital computers for a major portion of the simulation, all programming documents are reviewed. These documents consist of operational program data for simulation use and supporting logistics programs for computer and device systems repair. During this portion of the inspection particular parts problems are investigated and any chronic supply problems are noted. Along with these elements, training, manning, and support equipment are reviewed for adequacy.

c. Systems Test: The systems test portion of the inspection report consists of the actual revalidation of the training device performance. This revalidation is based on test criteria either generated especially for QA&R or criteria used for original acceptance. Special attention is given to discrepant areas discovered during the activity evaluation to determine the cause of any improperly operating systems. These tests constitute the detailed type of inspection to determine any unusual areas of wear and suggest the need for special maintenance attention or overhaul requirement.

d. <u>Configuration</u>: In modern training devices configuration testing can be applied in a number of areas. The most obvious test of configuration is the one established as replication of the real world. In the case of aircraft and weapons simulators, this portion of the report is prepared by comparing real world operational equipment changes to the simulation system. The report will generally state which real world system is being simulated and what operational differences exist between the real and simulated systems. In a training device, other configurations to be determined and maintained include the configuration of the digital computers and any dedicated processing systems. With the number of different configurations of the same computer systems now being encountered in training devices, actual configuration can sometimes be a significant support factor.

e. <u>Product Improvement</u>: The final portion of the report deals with required product improvement for the training device. Elements contained in this portion of the report are results of several separate investigations. First, various modification systems which represent the actual equipment that is being simulated are reviewed for applicable changes to the training equipment. These include airframe, avionics and powerplant changes for aircraft simulators, and include several other methods used by the Navy to modify actual weapon systems, ships or equipment. Also, during this portion of the report, operator and instructor personnel are interviewed for any change requirements in the trainer which may enhance or add needed training capability. Any maintainability or reliability modifications necessary to increase effectiveness or reliability are also investigated and included for action in this section of the report.

ACTION

Upon completion of the inspection, the senior inspector and technical advisor conduct a debrief for all personnel involved in the inspection or on site device support. During this debrief all sections of the QA&R report are reviewed for accuracy.

At this time, action assignments are determined to correct the discrepancies included in the report. Through the report, various activities involved in support of the training device are assigned action to respond to the findings of the inspection. The decision of action item assignment responsibility is based on which activity can best resolve the problem discovered. Following this debrief the senior inspector and technical advisor prepare a formal report, with action assignments, for submission to the appropriate training agent.

Under present QA&R instuctions, activities with actions assigned have 60 days from the date of the inspection report to respond by letter to the training agent with action taken. Action assignments are reported every 60 days until resolved. Figure 1 depicts the flow of the report submission and action item response.

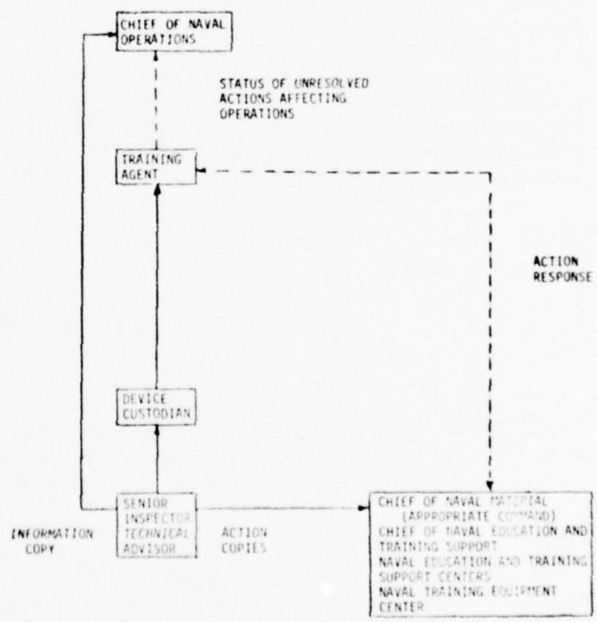

Figure 1. Report Distribution and ACTION ITEM RESPONSE

It is significant that the QA&R inspection team is not involved in any action taken to correct the problems found, nor the necessary response to the training agents. These are management oriented actions between organizations supporting the device and the training agent. This procedure preserves the needed objectivity of the QA&R team. Also note the response chain from the training agent to CNO. This line of communications is established to provide data concerning the status of unresolved discrepancies affecting training device operation. This line of communication provides a built-in warning system since, in instances where use of operational equipment is being avoided by simulation, a substantial impact on funds requirement may be encountered if simulation equipment problems are not quickly resolved.

THE CHALLENGE

It is at this point that the QA&R report becomes strictly a management document. The challenge to management is simply this, prioritize and apply appropriate resources to the action items assigned by the QA&R report. Management must always bear in mind that QA&R in finding discrepancies and assigning them as action items to those best suited to solve the problems is not engaged in simple fault finding but rather attempting to assign action to the organization best suited to resolve the problem and assure equipment in proper order to facilitate training. There may be times when action item assignments made by QA&R may appear to be embarrassing but management must maintain a professional attitude towards these action item assignments, and be assured that the Q&AR inspection aim is optimum device operating capability. The senior inspector and technical advisor who complete the inspection and the report are only interested in properly operating and supported devices that reflect current training need and configuration. As with any quality assurance organization, nothing can be accomplished to correct improper operation, defective systems, or poor logistics without constant and vigilant management attention.

Resource conservation through simulation is an attainable goal but only provided that simulators and training systems provide accurate, up-to-date, and continuous simulation through proper logistics and attention to training requirements. Without these elements the use of simulation becomes dangerous, unsafe and conserves nothing. To provide accurate simulation is the goal of all commands using simulation as a means to provide operational training. The Quality Assurance and Revalidation system is the only third party reporting organization providing action data to these commands. Management action on QA&R reports can and must provide better and more accurate use of simulators and simulation systems.

ABOUT THE AUTHOR

MR. K. G. LARRABEE is Head of the Quality Assurance and Revalidation Division for the Naval Education and Training Program Development Center. He has nearly 20 years of military and civilian experience with flight simulators and training devices. He was part of the team that formulated concepts, organized, and prepared the course of instruction for simulator technicians for the U.S. Air Force. He has worked in design, development, and logistic support of simulators and training systems for the Navy, Air Force, and NATO. Since entering Federal Service, he has been a Senior Field Engineering Representative and Digital Systems Support Coordinator prior to present position. He received his education at University of Maryland, California Polytechnic Institute, and Illinois Institute of Technology.

MULTICHANNEL WIDE-ANGLE COMPUTER GENERATED VISUAL SYSTEMS

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ABSTRACT

In today's visual technology there are many parameters, the values of which must be correctly chosen, to achieve an effective visual training simulator. Some of these parameters are resolution, brightness, contrast ratio, real image versus infinity image, collimation, field of view, field of view gaps, realism, target and area of interest fields of view, detectability and aircraft discernibility relative to slant range. True perspective and scene continuity across juxtaposed channels also are important parameters and are the subject of this report.

If single displays are used, scene continuity and true perspective is not usually a problem but most wide-angle visual systems today are composed of several optical windows, projectors or monitors to form a wide field of view while retaining good resolution.

When a specification requires juxtaposed displays, the designer must solve the problems of scene continuity with distortion-free perspective.

INTRODUCTION

The intent of this paper is to show the advantages of using a computer generated image generator (CGI or CIG) in a juxtaposed display system relative to scene continuity with perspective. This will be done by illustrating present, past, and future visual systems.

FUNCTIONAL CHARACTERISTICS

CGI technology inherently allows the extension of field of view through the use of juxtaposed display channels. Prior to the use of computed imagery, extension of the field of view required the use of wide field optical probes coupled into single or multiple cameras. The optical tradeoff necessary to achieve wide fields of view, and depth of focus, led to high sensitivity performance requirements and accompanying signal-to-noise limitations in the video cameras. Although a few organizations have made successful advancements in this area, the physical constraints of the technology are imposing.

The CGI technology released many of these constraints but at the same time brought some challenges of its own. To appreciate the CGI contribution to wide field-of-view simulators, through the use of multichannel displays, consider the previous systems discussed, all of which are multichannel visual systems. With that, couple your knowledge of other similar juxtaposed multichannel systems now being used in successful training applications. Whether the image generation is Contact Analog, STG, DIG, CIG, or CGI, or a combination of one of these with a camera system, computed imagery was the basis for extension to a wide field of view in the vast majority of today's successful multichannel simulators.

It is interesting to consider what constraints computed imagery frees and if it imposes constraints of its own. To answer both questions, consideration must be given to the projection geometry of the CGI system and how it relates to the display system in each case of the previously discussed multichannel simulators.

First, however, a review should be made of what a CGI system is and how it works.

CIG SYSTEM

The computer image generator consists of three major data processing cycles run concurrently, one in the general-purpose processor and two in the special-purpose processor. These computation cycles are slaved to the update rate and are repeated each 1/30 second corresponding to the update rate. The three cycles are connected serially and, therefore, are referred to as Frame I, Frame II, and Frame III operations. These relationships are shown in Figure 1. (The term "Frame" is used here for equipment and computation groupings and should not be confused with update rates.) Frame I operations are performed by software programs resident in the general-purpose computer system. A typical system consists of a single processor, peripherals, and software.

The primary purpose of the visual simulation software (VSS) is to provide overall control for the system during the real-time operation of a mission. To accomplish this purpose, the VSS must perform the following major functions:

a. Acquire vehicle and moving model position and attitude information and

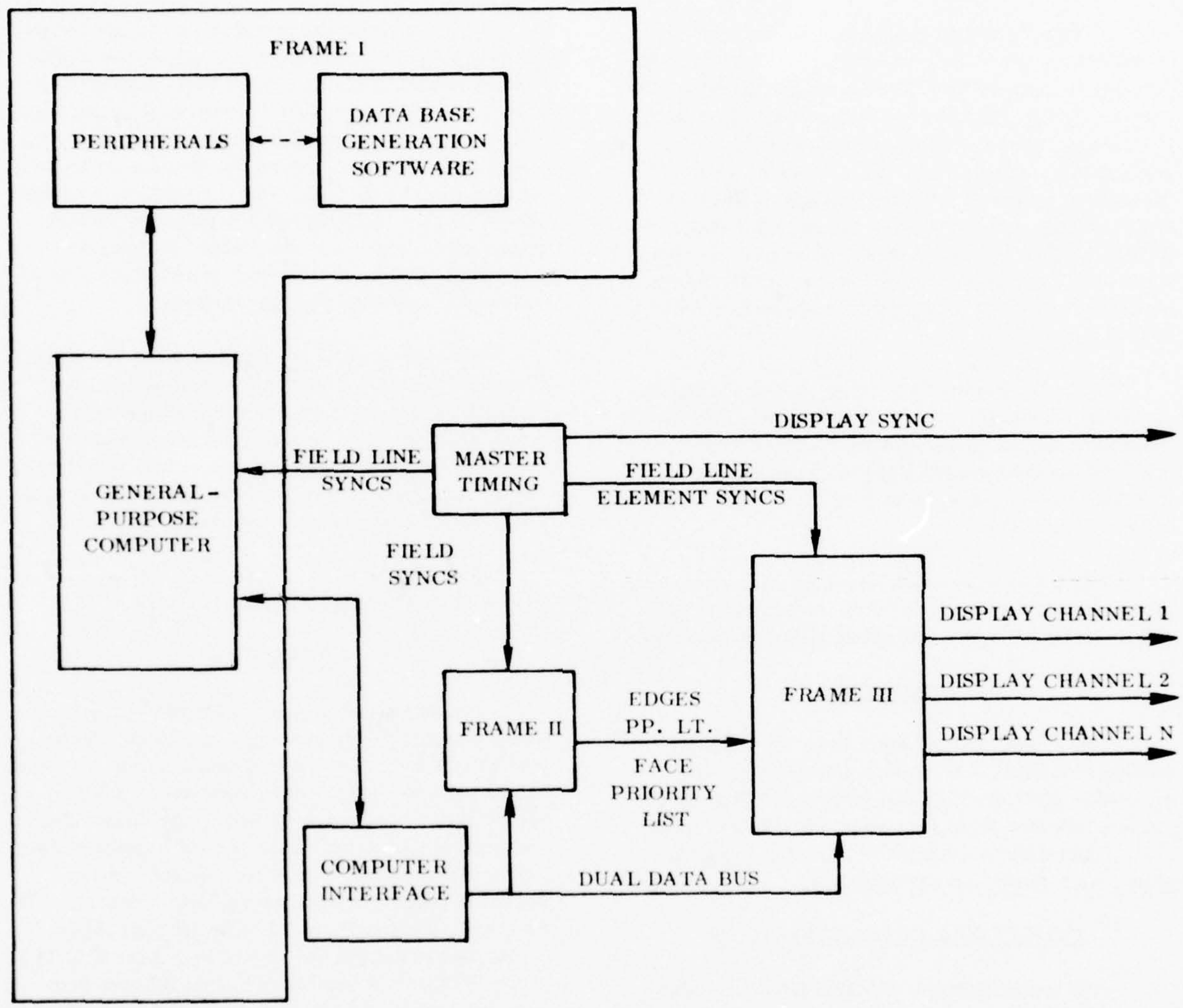

Figure 1. Image Generator Block Diagram

translate the information into the coordinate set and processing cycle of the image processing hardware.

b. Initialize the active gaming area data base.

c. Monitor controls, acquire and interpret commands, and implement any action required.

d. Transfer data and commands to the special-purpose image processor and monitor processing status, implementing any required actions defined by status or operator commands.

In addition to these real-time functions, the process of preparing the system to execute a mission has also been assigned to the VSS. The data received from the primary computer over the computer-to-computer interface consists of environment controls (i.e., cloud parameters, visibility, lighting selection, etc.); discrete controls; and position and attitude for the particular vehicle, such as aircraft, tank, seacraft, etc.

The VSS then processes these inputs to generate data for the Frame II and Frame III operations. Two special data buses provide the communication links to all functions within Frame II and Frame III for the general-purpose computer. These buses are used for on-line transfers during real-time scene generation and for off-line test and diagnostic data transfers.

The Frame II computations process a new two-dimensional image for each display channel during every raster period. The display channel images are true-perspective scenes of the modeled environment as viewed from the current position and orientation of the viewpoint and display channel view planes. The viewpoint and moving model(s) position and orientation data are received from the visual computer at the start of each raster period as a block of edge data words and as a block of point light data words. The number of words may vary from 1000 to 10,000 depending on the application. A face priority list is also transferred to Frame III at the start of each raster period. The face priority list contains the relative priority relationships of the faces bounded by the edges in the edge data word block.

The Frame III function converts two-dimensional image data received from Frame II into composite video that is synchronized to the display raster scan. The Frame III hardware then outputs up to eight channels to the displays.

DETAILS

With an understanding of the CIG, we will now return to the details. Projection geometry is shown in Figure 2. The data base, a mathematical model of the environment, is transformed to a two-dimensional image plane located at some defined position with respect to an eyepoint. The angles subtended by this image plane at the eyepoint are the field of view of a single computed channel. (It is analogous to the photo-sensitive surface of a video camera in a camera/model system.) To extend the field of view, it is merely necessary to add image planes forming a polyhedral array with the eyepoint at the geometric center. This is analogous to a camera system containing a concentric array of lenses and cameras. Packing constraints, finite separations or overlaps at the channel boundaries, and distortions at the boundaries limit the extension of camera systems to multiple channels. None of these constraints of limitations is inherent in the computed images. Distortion is negligible since the transformation from the data base to the image planes is limited in accuracy only by the number of bits chosen for calculating the projections and defining the image planes.

Subsequent to the initial transformation from the data base to the image plane, the CGI system performs additional important functions. For example, perception of the third dimension, depth, is preserved by determining the priority of environmental models, lights and terrain. Another important function is the transformation of the image to a raster, which allows video transmission and display.

The display devices used in the multichannel juxtaposed systems are generally designs of monitors or projectors whose components were initially developed for television or radar applications. These are combined with special optical systems developed primarily for simulation applications. One of the simplest of these combinations is illustrated by Device 2B35 Training System. In the 2B35 system, Figure 3, juxtaposed projection screens combine the images and represent a simple unity transformation of the mathematical image from the computed image planes to the projection screens.

The Eye Reference Point (ERP) of the simulated cockpit must correspond to the computed eyepoint. To fix the ERP with respect to the

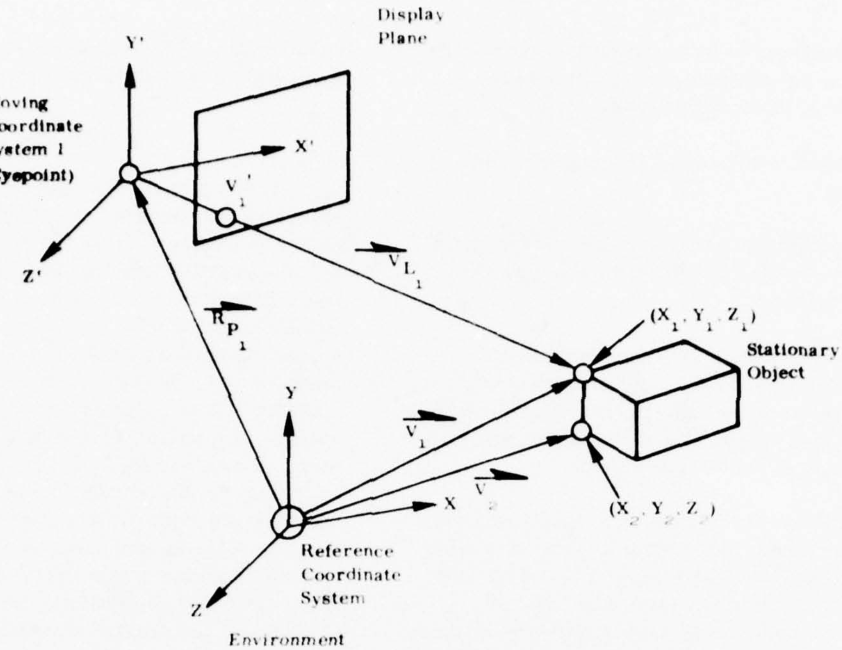

Figure 2. Environment Coordinate System

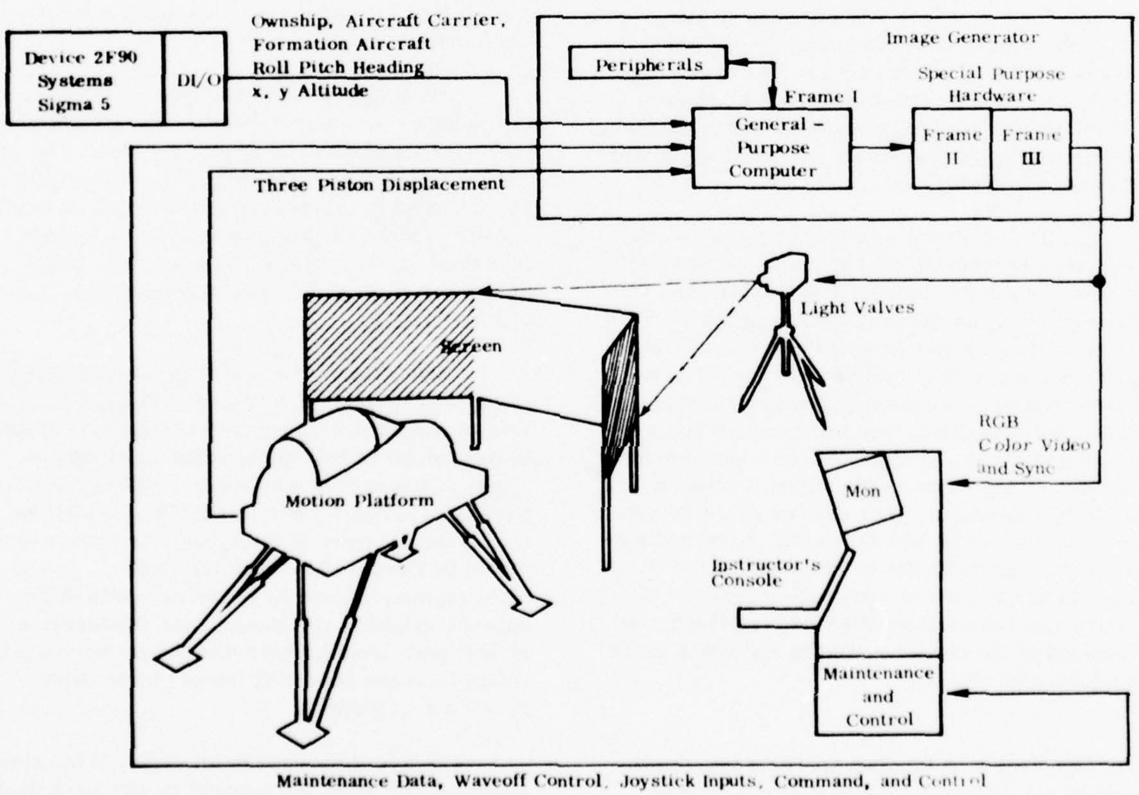

Figure 3. Device 2B35 System

screens would have required the screens and projectors to be fixed to a moving platform. The CGI projection transform provided an alternative solution by allowing a dynamic redefinition of the image plane position with respect to the eyepoint that tracks the ERP motion with respect to fixed screens.

An added simplification of this system was inherent in that the color television projectors used (GE model PJ5000) were designed for flat-screen projection. Since the linearity in these projectors is rigidly controlled to optimize color separation, the distortion in the projected image is low.

The two types of distortion present were pincushion (due to slight lens distortion) and small raster drifts in position and size. Since the pincushion was near one percent, a slight horizontal mismatch was evident over one to two picture elements on each side of the seam. Vertical size was adjusted to bring vertical mismatch to within one line. Horizontal size was adjusted to minimize the horizontal mismatch at a location five degrees to ten degrees above and below the horizon.

The drifts in size and position were stabilized by an edge match control system, Figure 4. This control system used photo-resistive detectors placed at the edge of the screen in the horizontal overlap area to sense video cursors. These cursors were added to the video by the CGI outside the computed image area of the raster. The control electronics algebraically added the error signals to obtain both size and position control signals in the vertical and horizontal. These signals were used to change the sweep voltages and position biases in the projectors to achieve geometrically stable operation.

An example of the use of a polyhedral array of image planes having a larger number of facets is the ASPT system. In this case, the optical system which combines the images, is an In-Line Infinity Optical System (ILIOS) array, Figure 5. Since the ILIOS transforms its focal surface to infinity, it is necessary to transform the image plane to the ILIOS focal surface and still preserve the correct angles. To visualize this, assume that the CGI image planes are mapped to infinity such that all angles subtended at the eyepoint are preserved. The ILIOS must perform the same mapping function. If the image is assumed to be initially at infinity, it can be mapped through the ILIOS to the focal surface. Since the plane beamsplitter images the focal surface of the ILIOS to a sphere concentric with and one-half the radius of the ILIOS spherical beamsplitter, the mapping to this focal surface is used to calculate the transformation. Referring to Figure 6, the mapping of the image plane at infinity to the focal surface can be represented by a tangent image plane at the focal surface with the images mapped to the surface through the center of curvature.

In ASPT, the CRT phosphor surface radius of curvature is the same as the ILIOS focal surface. The scan lines and columns of picture elements are, therefore, mapped as great circles on the CRT surface. Two choices were available to accomplish this transformation; correct the sweep to follow the correct scan line and picture element positions, or use a spherical rear projection screen with a video projector whose lens are located at the center of curvature. Both approaches presented risks, however, the risk of extending CRT technology appeared lower.

In the ASPT system the versatility of CGI again became obvious. In order to maximize resolution, the raster was aligned parallel to one edge of each pentagonal facet. This approach most efficiently covered each facet's field of view with the raster. The juxtaposed rasters, therefore, were put at different angles and the rasters center was not coincident with the pentagonal facet center. This task of symmetry caused no problems of inaccuracy in the CGI system since the only requirement was to correctly define the image plane field of view for each facet with respect to the eyepoint.

Added flexibility in alignments were allowed by this ability to define the image planes. The alignment of each individual channel is performed by using theodolite located at the center of curvature to measure and correct grid intersection locations. It is a tedious and time-consuming procedure. Due to anomalies peculiar to each ILIOS facet and CRT/electronics channel, the alignment is neither perfect nor optimized to any particular viewing location. An alignment algorithm has been devised which redefines the image planes to optimize the overall alignment. Input data is a set of error measurements recorded for selected grid intersections in each channel. After alignment, the stability is maintained by low-drift electronics and the rigid structure which holds the CRT's and optics. Periodic maintenance is required to perform realignment but it is infrequent since the stability requirements were considered in the initial design of the CRT/Electronics.

The next two examples of juxtaposition are represented by the Boeing and MRCA visual systems, Figures 7 and 8. The displays in these systems use a 26-inch high resolution shadow mask CRT. The images from two or three CRT's

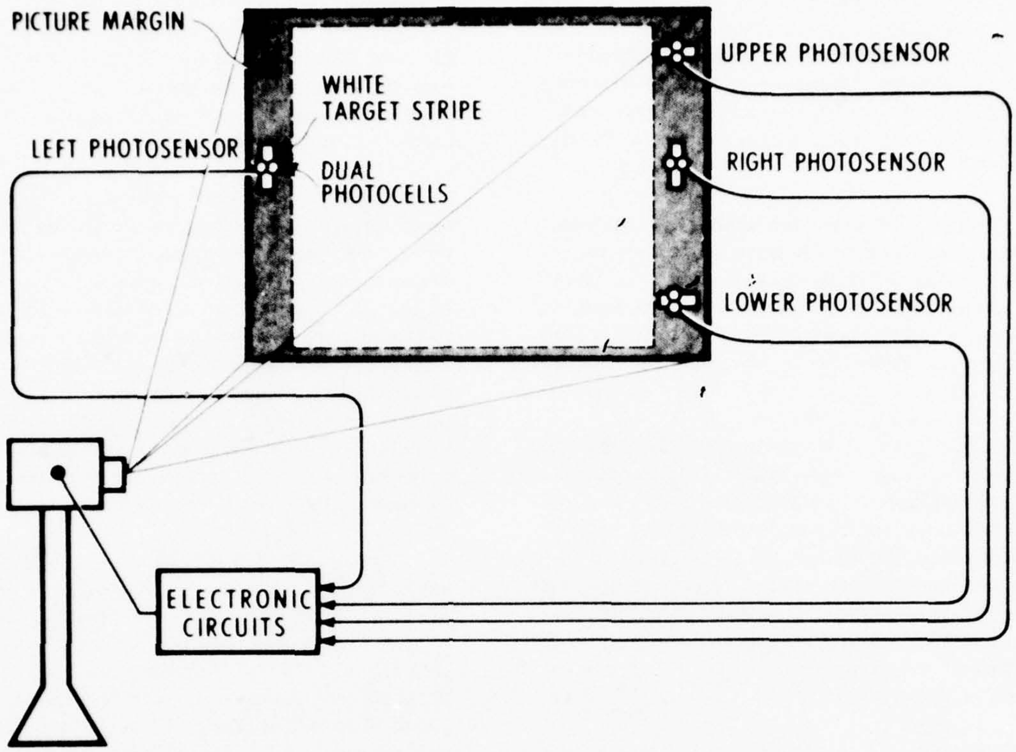

Figure 4. Edge Match Control System

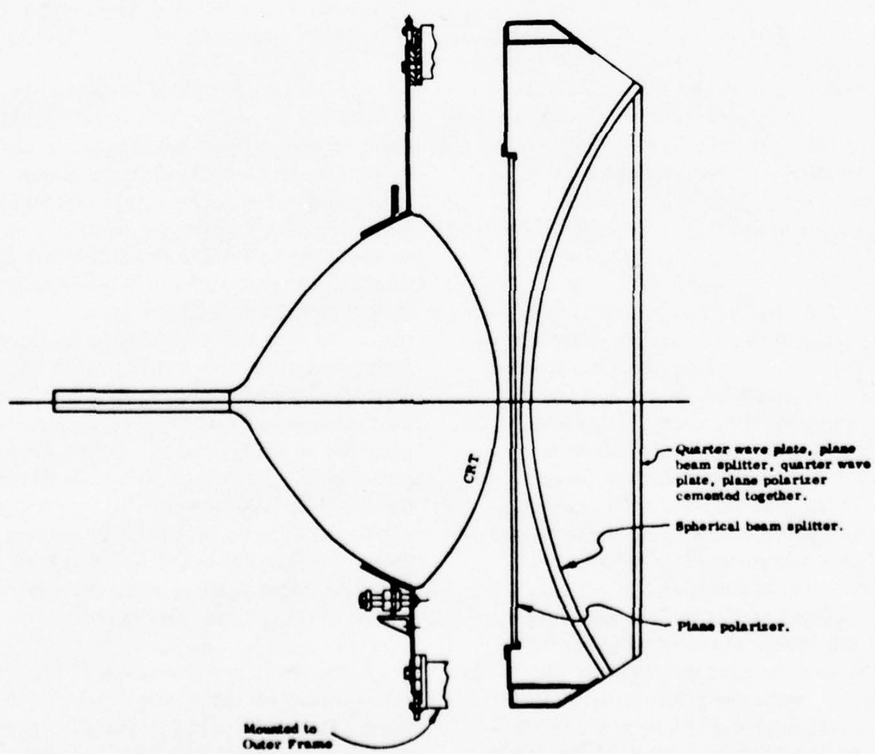

Figure 5. Cross Section of Typical Farrand In-Line Infinity Window

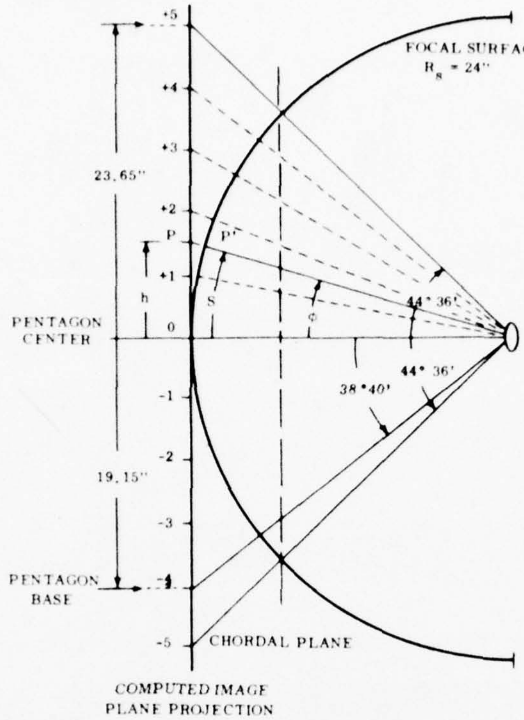

Figure 6. Mapping of Image Plane to ILIOS Focal Surface

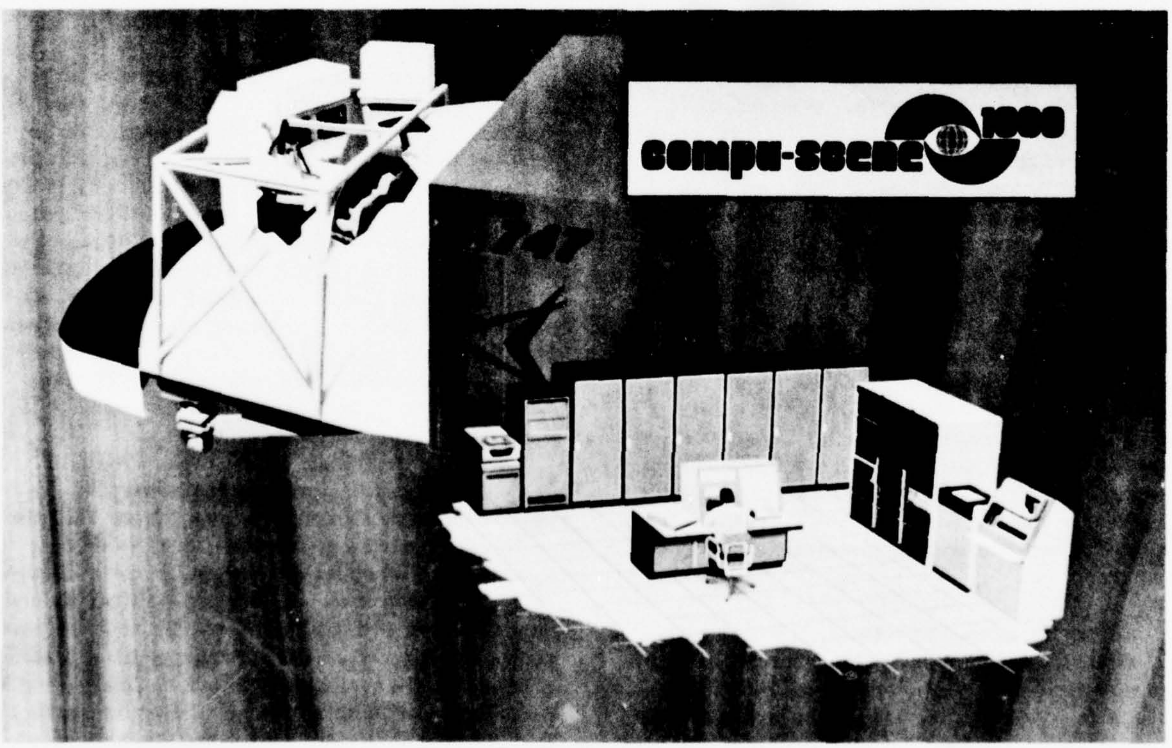

Figure 7. Boeing Visual System

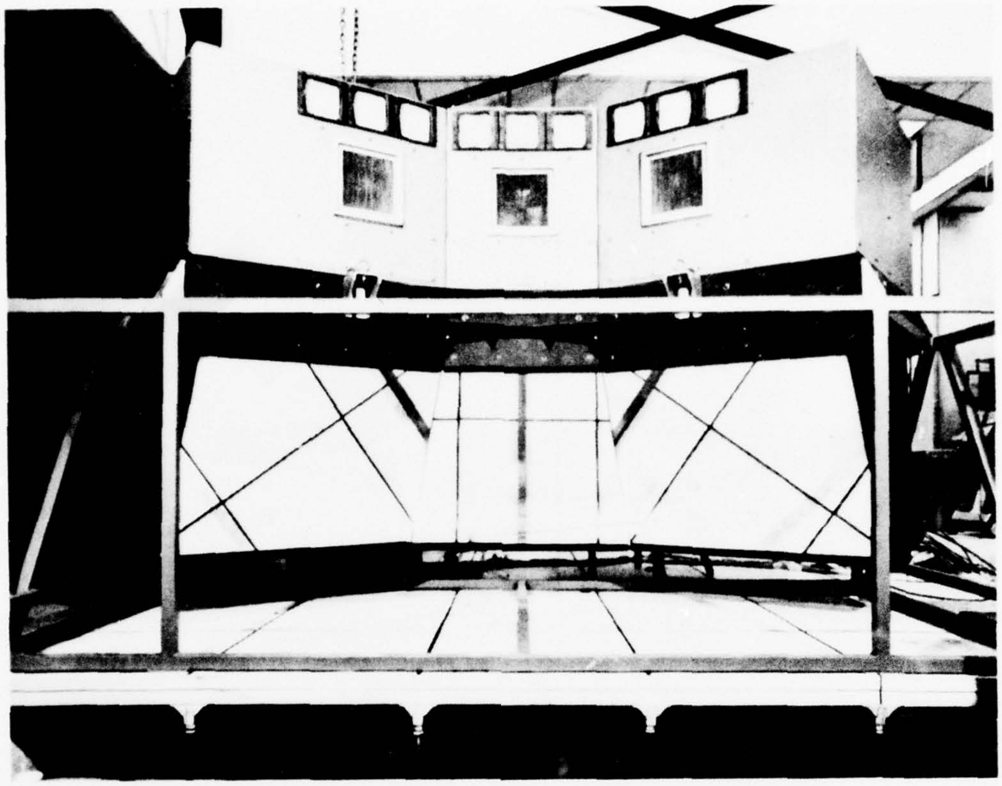

Figure 8. MRCA Visual System

are combined by modified 45-degree beamsplitter/ spherical mirror optics. The CRT's are constructed from funnel and face plate elements used in commercial tubes to minimize cost. For this reason the CRT phosphor surface does not lie in the optics system focal surface and the location of the CRT and focal surface images are shown as transformed by the plane beamsplitter (see Figure 9). If the eyepoint is located at the center of curvature of the spherical mirror, the correct image location on the CRT surface is the projection line through the eyepoint to the tangent image plane similar to the ASPT mapping. In order to increase the instantaneous field of view, the ERP is located closer to the mirror than the center of curvature. Location of correct image points was determined by computer programs, and the CRT/ electronics were designed to achieve this mapping. Accuracy and stability requirements of the sweeps were nearly the same as the ASPT system in order to achieve acceptable juxtaposition accuracy of images.

From the preceding efforts, it was apparent that extensions of the visual simulation technology into wide field of view, color presentations with acceptable resolution and brightness would require large expenditures for high risk development efforts or a unique approach. One approach which was investigated is shown in Figure 10.

Video projectors form an image on a juxtaposed array of field lenses. A wide-angle lens at the center of the array relays the image to another wide-angle lens located at the top focus of a double ellipsoid consisting of a mirror and screen. An image is formed between the output lens and mirror such that the mirror projects the image to the screen. Since the mirror and screen share a common focus point and have the same ellipticity, the pilot located at the bottom focal point of the screen is presented an image with minimum distortion. From first order analysis, the chief rays in this system will be located at angles corresponding to the initial calculated positions.

A full scale prototype of this system was built which confirmed the mapping (see Figure 11). The prototype consisted of available lens, video projectors and a custom-built screen. A peak-screen gain of nine was achieved with good uniformity and no distracting surface blemishes. On axis entrance pupil chips a function of field angle was not accommodated by the available field lens. This caused a per channel brightness fall-off which was distracting. Lateral chromatic aberration and astigmatism

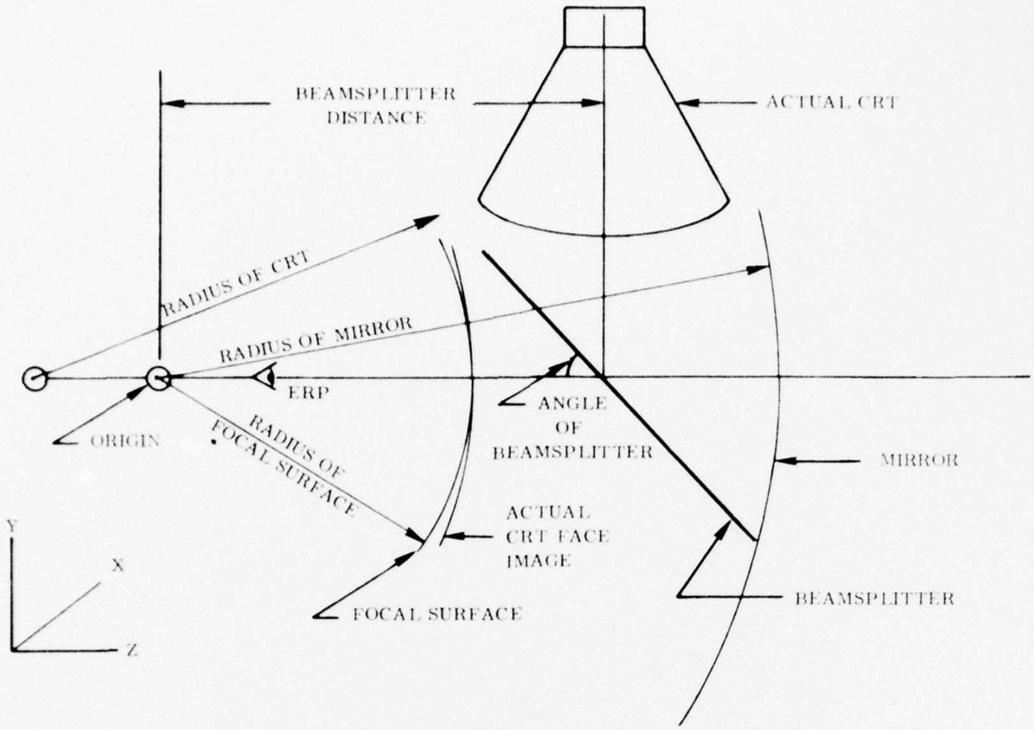

Figure 9. Virtual Image Display Optical Schematic Showing Input Parameters

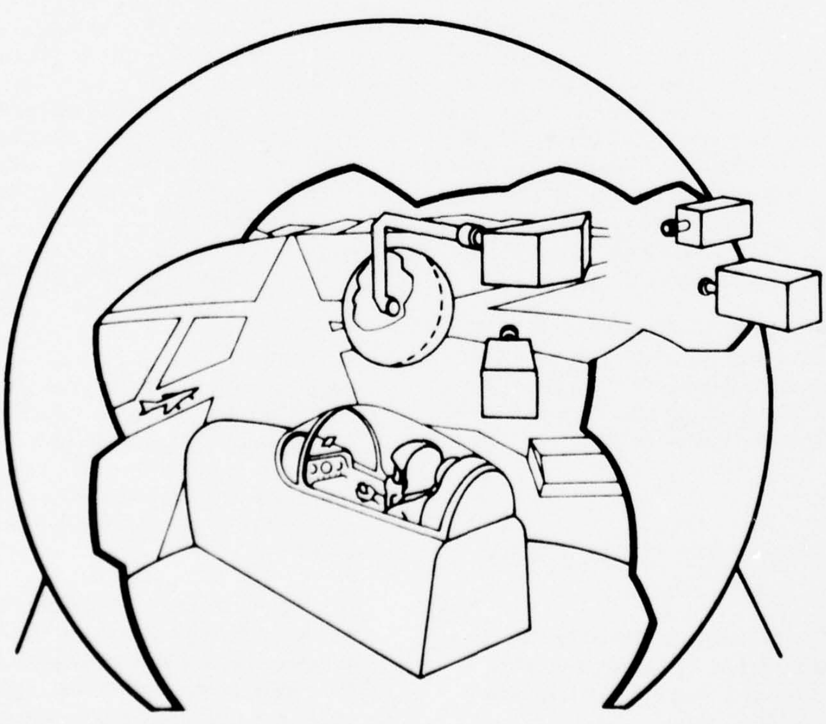

Figure 10. Wide Field, Color Display System

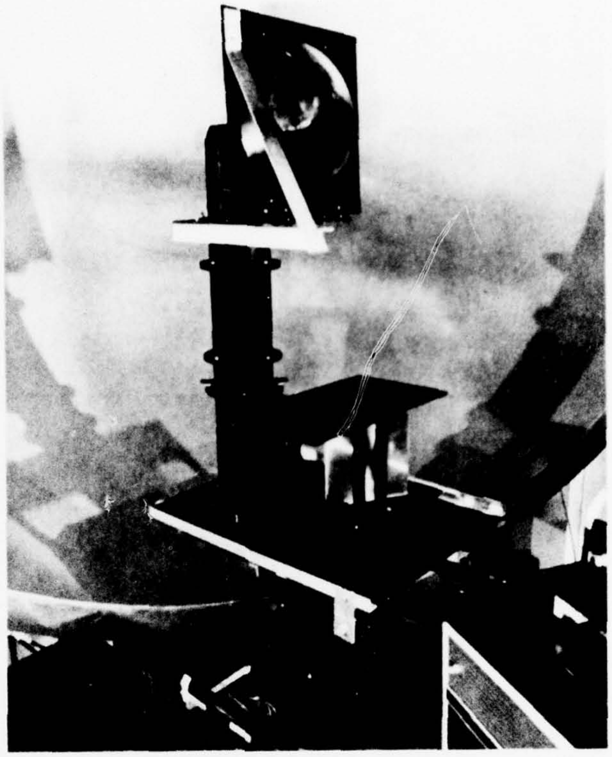

Figure 11. Display Breadboard

in the wide-angle lenses limited acceptable performance to the forward field of view.

An alternate tradeoff in this type of system is to compensate for distortion on the screen and reduce the number of optical elements required in the system. Since the raster of a single gun color light valve cannot be shaped, it is necessary to achieve mapping in other parts of the system. For example, a camera model system allows the raster shaping in the camera. Analogously the CGI system should allow shaping in the image plane.

This concept leads to the discussion of the AWAVS system in which this flexibility of the CGI will be improved and implemented. This implementation of the CGI mapping capability will make the AWAVS system the forerunners in CGI, dome technology.

AVIATION WIDE-ANGLE VISUAL SYSTEM (AWAVS)

The Aviation Wide-Angle Visual System is a complex camera model, CGI dome visual system built by Singer-Link and General Electric (see Figure 12).

General Electric's contribution to the system is the computer image generator and the light projectors. This part of the visual system is significant by the fact that this is the first dome, GE light valve projector system where the CIG will generate partial mapping corrections from the image plane to the pilot. The feature, in turn, will allow future dome, CGI, GE light valve projector systems to be used in both color and monochrome.

FUTURE VISUAL DISPLAY SYSTEM REQUIREMENTS

Due to the demand and requirements of training in visual simulation today, there is an everlasting need to produce sophisticated simulators. But the question is,"What is the optimum visual simulator?" Of course this question is followed by two more very rapid questions. "What is the training requirement and how much will the system cost?"

In the display area alone the requirements for aircraft and tanks seem to be the same old parameters that have been plaguing visual systems for years; color, resolution, brightness, field of view, eye pupil, infinity image or rear image.

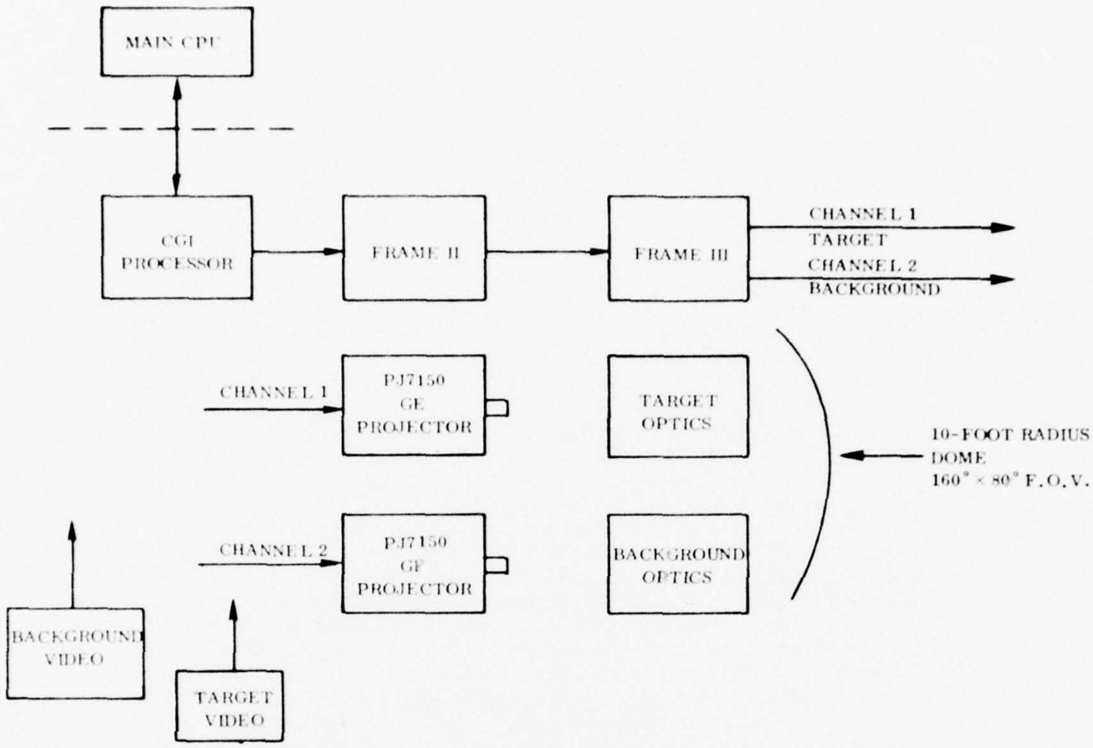

Figure 12. Simplified Display CGI Block Diagram

The above parameters themselves share a wide variation of contention within the users.

If the user must have a large continuous field of view for good trainability, he has two prevalent display choices today; a dodecahedro with pentagonal windows or a dome system with multiple projectors. Both systems lack what the user would ultimately want in performance. But if his pocketbook could afford it, and his schedule were long enough substantial improvements could be made. Consequently, the display parameters mentioned require more research and development to achieve the requirements of future visual systems.

In the image generator area some of the improvements in parameters such as potentially visible edges, variable size point lights, number of edge crossings per scan line, number of raster lines, and number of display channel drives per computer image generator need to be expanded by time sharing or other techniques that will keep the economics reasonable.

With continued improvements in the display and image generator areas, visual simulation will expand, thus giving great savings in manpower, money, material, and in particular, fuel.

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DESIGNING DIG IMAGES FOR SYSTEMATIC INSTRUCTION

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SUMMARY

Digital image generation systems can provide most of the visual information needed in performing and learning flight tasks. This paper discusses a methodology applicable for the selection of visual information for DIG representation. The methodology is designed to produce scenes which optimize learning through various stages and complexities, by identifying minimal cues for each task, subtask, and trainee level. Added capabilities of DIG systems include enhancement of the performance feedback cues normally available in the real-world task, and facilitation of learning by the provision of synthetic feedback where it is normally deficient in the real world.

INTRODUCTION

Complex operator skills are developed in stages, each differing from the others in degree of cognitive, perceptual, and motor involvement, in their general utility in the overall system environment, and in the kinds of demands they make on the training situation. Fitts (1) described three distinct phases in skill acquisition. In the cognitive phase, the intellectual aspects of the skill are learned. In the fixation phase, patterns of motor action are refined and fixated with respect to unique patterns of stimuli. In the final stage of learning, motor actions are automated, to the extent that they can be carried on without conscious awareness or intervention.

During the cognitive stage, important elements of many visually oriented tasks are learned through the association of specific actions and performances with representations, either verbal or graphic, of the visual cues describing the course of the action. Motor skills are learned through practice in the use of the system controls, or simulated controls, in such a way as to cause the cue display (real or simulated) to perform the functions defined in the cognitive stage. As Gregory (2) has noted, skills are knowledge-based predictive behaviors in which the function of stimuli, or cues, is to define the actions required in a given situation. Practice and learning produce performance which becomes increasingly like the standard defined for the procedure, task, or maneuver. When the stimuli that cue a specific behavior are perceived as similar to those encountered in the operational setting, skills developed in practice become transferable to that setting.

Stimuli viewed directly in the real-world system environment are vital in the performance and training of many vehicle and system operator skills. Many high-performance military vehicles must be controlled totally through the interpretation of real-world visual cues in much of their operational envelope. In these systems, the fixation of motor skills in relation to visual information is crucial in the development of effective skill levels. Traditionally, the fixation of visual-motor skills has occurred in real-world settings in vehicles configured for training and refined and automated in training exercises conducted in (sometimes severely) limited training settings.

Early developments in simulation technology permitted the substitution of safe, economical, and convenient settings for real-world training at significant savings. Advances in the technology made possible further increases in training efficiency and cost-effectiveness, but primarily in tasks in which visual cues were either lacking or of minimal significance. As recently as 1977, Caro (3) was able to say, with some justification, that no research had conclusively demonstrated the training value of visual simulation. Visual simulation systems clearly demonstrating positive training value have only very recently come into being. Wheal (4) expressed the opinion in 1976, after surveying a number of simulator problems, that "current visual displays are roughly a generation behind the rest of simulator technology."

An obvious reason for the relative neglect of visually cued operator skills is the inability of any simulator visual display medium to produce visual scenes equalling or even approximating the complexity of any but the simplest real-world scenes available to system operators. But a more important reason is the failure of system designers and users to identify the real-world scene elements and scene dynamics required for effective training. This stems to some extent from the assumption that transfer of training depends on the degree of objective similarity between the training and operational environments, when in all probability the similarity need only be subjectively perceived for effective transfer. In addition, of course, it is apparent that complex skills develop not only in qualitatively unique stages but in meaningfully definable, discrete components. These discrete components can frequently be associated with much simpler visual information than is ordinarily seen in the operational setting. In effect, the dynamics and configuration of these simple cues can be abstracted from the real-world scene, to simplify and systematize training.

Caro (4) cites the research of Flexman, Matheny, and Brown, who taught contact landings in the T-6 aircraft by manually tilting a simple blackboard representation of a runway trapezoid, mounted in front of an SNJ OFT; Caro also cites experiments in which purely instrument training,

conducted in a simulator, reduced requirements for visual flight training in both rotary- and fixed-wing aircraft. Finally, Smith, Waters, and Edwards (5) were able to reduce visual flight training requirements in the T-37 without using any simulator at all, in the traditional sense. The overhead traffic pattern was taught with a combination of text, sound/slide, and 8mm motion picture materials, resulting in a significant savings in flight time requirements. Obviously, high fidelity, in the classic sense, is not needed for effective visual training.

The Nature of Visual Cues

Visual cues are changes in visual scene elements, resulting from the operation of the system's controls or from changes in the system environment, to which the system operator must respond. In many real-world visual scenes, visual cues are highly redundant; control is possible by attending to (or displaying) only a part of the normally available scene, provided the parts of the visual scene that are made available are perceived as varying in the same way that the total visual scene would vary under similar circumstances. In many flight tasks, as in other operator tasks, it appears that up to a point, visual cues can be drastically abstracted for training. A simple checkerboard display representing the terrain (5) appeared to provide sufficient cues to altitude, altitude rate, and ground velocity in a complex air combat task. In the same situation, the projected view of a scaled, articulated model barely provided the degree of detail required in the target image to simulate air-to-air maneuvering and gun tracking. In the case of the terrain image, cue requirements were minimal for the ACM task; in the target aircraft display, skilled pilots needed as much information as could be provided, to perform as they were able to perform in the aircraft.

Visual Cues and Skill Level

Novice pilots appear less likely to be able to use complex control cues, while skilled pilots seem to have learned to use cues not readily recognized by the novice. The novice perceives little of the flight environment until he has had time, experience, and guidance in recognizing the dynamic relationships among control inputs and specific environmental changes. As he becomes more skilled and more experienced, he learns to incorporate more and more environmental information in his perceptions.

Ideally, the simulator should provide an opportunity for the student to develop these basic perceptions in uncluttered settings, until such time as he is able to deal with clutter per se, and to learn to recognize elements of the clutter as meaningful. Simulator instructors, flight instructors, and training programs have traditionally provided these opportunities to a degree, by adapting training settings to the capabilities of the student at each stage in his development.

In general, simulators are equipped to permit the adaptation of training to student capabilities better than airplanes, and some simulator systems, properly programmed, permit adaptation better than others. Visual systems have been less flexible in this respect than motion, aural cue, and instrument systems. They have almost always provided cuing information defined more by their own unique capabilities and limitations than by the needs of students of varying levels and kinds of ability.

Digital Visual Cues

Digital image generation systems are unique in a number of ways, but unquestionably the most important characteristic of these systems is their flexibility. Camera-model and film systems, while providing high-quality visual scenes, cannot be readily reprogrammed; once defined, the applicability of a given model or film sequence is limited to a specific training situation. Digital systems can be programmed for an almost infinite number of levels of complexity, and in addition, as Roscoe has shown (6), they can be programmed to provide augmented feedback information to enhance both training and transfer. Given this capability of digital image systems, it becomes necessary to identify the cues required at each level of skill development, and to define the kinds of natural and programmed feedback needed to enhance the learning of each skill to each level required by the mission being supported.

Many visual simulation systems have been designed to incorporate all of the visual information possible, but sometimes the level of detail has been inconsistent with the ability of the display system to process it, and to make it vary realistically with control inputs. Sometimes, important information has been left out for the same general reason: the medium could not handle the storage or the display problem, in some critical area. Obviously, digital image systems will not be able, for a long time in the future, to display full-fidelity representations of complex visual scenes. Because they can display nothing before the scene requirement is thoroughly defined, however, they have the advantage of requiring a clear definition of the scene requirement before they are programmed.

The problem of programming visual cues is two-fold. First, a clear definition is required of the information needed to support specific responses and to facilitate response learning. Second, enough cues to each action must be included to prevent the induction of illusions. Ritchie has discussed in a recent paper (7) some of the ways in which illusions can result in visual systems in which important cues are missing.

Digital image systems can minimize the effects of these problems by programming only those cues which are essential for specific levels of practice, in specific tasks and subtasks. Digital image systems thus place a special responsibility on the visual system designer for defining in detail the cues needed for learning in each level of skill and student sophistication, and for precluding the induction of illusions through the deletion of cues which are not primary for the task, or which are incompatible with the available storage and display media. Task analysis has been a nominal requirement for many years in the development

of training system concepts, but little attention has been given to the identification of specific scene element requirements for specific tasks and specific learning contexts. Future visual simulation systems will have to be designed to fulfill specific task requirements, based on task analysis data, and they will have to permit some trial-and-error in the development of scenes which are both responsive to the training requirement and economical.

The problem in trial-and-error design is that it is not, in the long run, practical or economical, because it is almost impossible to do within a realistic training context. In the final analysis, it will be necessary to design digital visual scenes as the training system is designed, to provide the kinds of visual cues needed in each stage of training. Task analyses for training system and training equipment design will have to be, finally, real training task analyses.

TASK ANALYSIS

R. B. Miller, over twenty years ago, defined the requirements for and the uses of task analysis in system development and training system design. Although he defined quite clearly the differences between task description and task analysis (8), many task analysis efforts during the intervening years have been limited to task descriptions, in which tasks are described in detail, with less attention to task dynamics than is required in training system development. Emphasis is required now on the analysis of the behavioral aspects of tasks and of the learning functions involved in optimizing the development and maintenance of task proficiency. This is necessary in all simulation applications, but especially in visual system design.

Flight tasks are typically difficult to analyze, because the source of data is so frequently skilled pilots whose skills are essentially nonverbal. More attention must be given to the fundamental dynamics of the tasks and the task learning processes to which the simulator is to be applied. The analysis of tasks for visual system design can be approached in many ways, but consideration of the following points can facilitate the systematic development of visual system design concepts:

1) Available Cues. The simulator cannot, within the technology available now or in the near future, provide all of the visual information available in many flight regimes. Nap-of-the-earth flight, terrain avoidance, air-to-ground, air-to-air, and even hovering maneuvers involve more information than can be represented in a simulator. These maneuvers and others, however, must be analyzed for their visual information content, so that the analyst and the designer can begin to visualize the task performance problem, and the learning problem. Some cues can be stored photographically for analysis by expert pilots, instructors, students and training analysts. Figure 1 is an example of a scene having training implications, and implications for visual system design. Although it is not in color, it does provide some insight into the complexity and information content available in a relatively simple flight situation.

Figure 1. Normal VFR Landing Scene

2) Task Functions. Since the student using the simulated visual system must learn certain dynamic relationships among the behavior of the visual environment and the inputs made on his controls, it is necessary to establish the functions which he is expected to perform within the tasks under consideration. Identifying specific task functions can help in the identification of the cues associated with the functions and can help in defining those which are, in fact, minimal or essential cues. Since skilled pilots tend to have difficulty in noting or recalling their responses to visual cues, it is useful to review many tasks with instructor pilots, and also with students, where possible. Instructor pilots, in general, consciously attempt to identify the cues to which the student should respond, so that they can be identified by the student in the context of real-world clutter. Also, experienced pilots frequently can recall circumstances in which many scene elements were missing (flying over the desert, in limited visibility, over fields of hay, over water) and which provided either inadequate or confusing cues. The recall of such experiences can be especially useful in establishing the relationships among specific task functions and the visual information available in the performance of the function. By the same token, students at various stages of learning can frequently recall their reactions to visual scenes, and the scene elements they learned to respond to.

While many flight tasks are complex, and require highly developed perceptions and perceptual-motor skills, most involve some combination of functions with which discrete visual cue requirements can be associated. The pilot in almost all flight control situations must eventually learn to control attitude, spatial position, geographic position, ground velocity, flight path, altitude rate, closure rate, and flight path with respect to obstacles along the route. Individually, the essential cues to each of these functions are relatively simple. In Figure 1, some of the more obvious cues to flight control in landing can be identified. Some are redundant but, because of the size of the picture, the lack of color, and the fact that it is static, many useful cues are missing. Figure 2 is an artist's

concept of perhaps the simplest digital image scene that could be used in training parts of the landing task. Gross cues needed in the control of pitch and roll and position on the

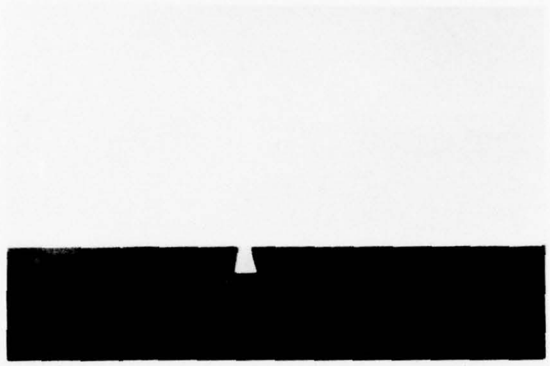

Figure 2. Landing Scene with Minimal Visual Scene Content

glideslope and centerline, and some of the cues to altitude and closure rate, are available in the geometry of the scene and in changes in the size of the simple runway image. The cues displayed in this picture, and those which would be available in a dynamic scene, are adequate for teaching some components of the landing maneuver, under ideal circumstances. Figure 3 shows more cues to position, closure, and flight path, and introduces additional cues based on the absolute size of some elements viewed by the student in the real world. Taxiways, buildings, and runway

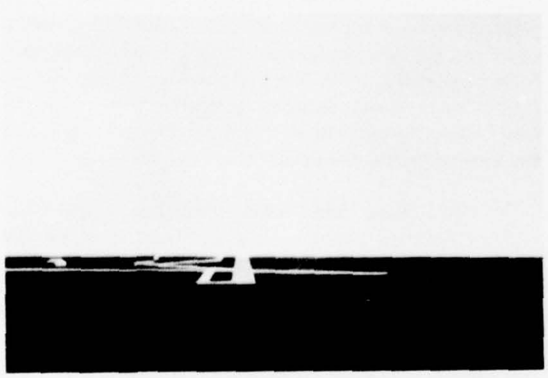

Figure 3. Landing Scene with Added Geometric and Textural Cues

markings add cues which are probably redundant with the simple geometric cues, but which require less interpretation. In addition, more cues to position are provided by the relative motion of scene elements, permitting the perception and learning of more cues than was possible in Figure 2. Figure 4 is a more complex scene, and while it is probably little better in training the task elements that could be trained in a scene like Figure 2, it provides better

Figure 4. Landing Scene with Added Textural and Parallax Cues

position and closure cues, which are important in flight conditions that are less than ideal. The cues provided in this scene would permit the learning of basic flight control skills and some of the skills required in landing at this particular airport. With wind, turbulence, and the time-sharing required in dealing with system failures, these extra cues provide a better opportunity for the student to grasp the dynamics of the landing situation. In addition, these extra scene elements tell the pilot about some of the unique problems encountered at this airport, where the approach is made over sloping terrain. Novice pilots frequently take altitude and altitude rate cues from the terrain under the approach, flying glidepaths well below the ideal glideslope. The addition of scene elements representing trees, roads, fields, and buildings under the approach path permits the student to learn the set of task elements relating to visual scanning and cross-checking, not possible with a simpler visual scene.

Figure 5 illustrates another need for more than simple cues in the visual scene. Since pilots must fly in less than ideal conditions, they must have practice in dealing with marginal conditions. Another task element in the landing maneuver is the use of minimal and fleeting cues in perceiving and controlling the position of the aircraft. The visibility conditions illustrated in Figure 5, superimposed on Figure 2, would almost preclude any learning at all. The detail in Figure 4, over which the clouds are laid, would permit the student to learn to recognize his position, and to make realistic responses.

Figure 6 deals with another set of task elements which become important as the aircraft moves from the

Figure 5. Visibility Effects in the Landing Scene

flight environment to the ground. Markings on the runway, familiar in shape and size, the stones on the embankment, and the motion of the approach light fixture with respect to its immediate background provide cues to lateral and

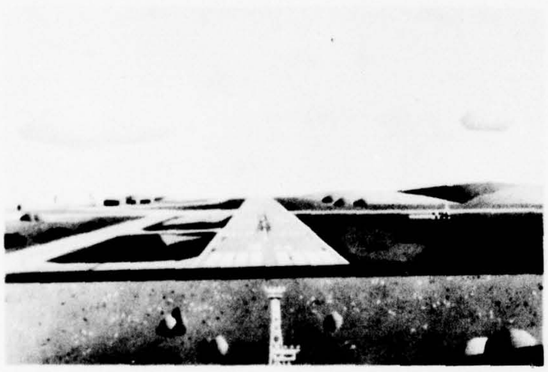

Figure 6. Breakout of Textural Scene Elements

vertical positions and, equally important, to rate of closure with the touchdown zone. This scene contains a great deal of information, but much less than is contained in the real-world view it represents. The information it contains is directly related to skill elements identified with the landing task, and it is well within the capabilities of reasonably economical digital image generation systems. Figure 7 contains even more information in the form of cues to altitude rate. Scene elements portraying runway lights, tire marks, runway grooving, and patches of color in the grassy areas are, in a limited sense, textural cues. More than this, however, they are cues to the precise altitude and motion of the pilot's eyepoint in relation to readily recognized real-world scene elements. This scene, while relatively complex, still does not come near to using the total capacity of even a simple digital image generation system.

3) Minimum Cues. Figures 2 through 7 portray scenes related to one flight maneuver. Figure 2 represents the minimum set of visual information required in practicing some elements of the landing approach task, under ideal flight conditions. Figure 3 also represents a minimum

Figure 7. The Visual Scene at Touchdown

set of cues relevant to other task elements relating to motion parallax and the breakout of familiar detail with closure. Each of the other pictures represents the minimal cues which seem to be required for training various other task elements. Minimal cues are important in minimizing the cost of the system, but they are even more important in supporting systematic learning. Digital systems can provide cues of varying content and complexity, commensurate with the student's ability to perceive and apply them in practice, and to identify them as key elements of the real-world visual scene. Minimal cues must not be defined as the minimum information varying in the scene with control inputs, but rather as the minimum information, varying with control inputs, which the trainee can readily perceive. Once he does learn to perceive them, other cues can be added, to provide the minimal scene content relevant to the next task element to be learned.

The experience and background of the student who is to be trained is an important consideration. Simple sets of cues are more likely to be acceptable for novices than for skilled pilots who have already learned to reconcile the redundant information contained in real-world visual scenes. The student can learn to recognize simple cues as they are embedded in the real world, but the skilled pilot may have difficulty in interpreting them out of context.

4) Part-Task Training. Visual simulation systems are usually associated with crew trainers and mission simulators, but the flexibility of the digital image approach lends itself especially to part-task training. Digital images

can provide elementary cues for initial task training, and augmented feedback cues to facilitate learning. As the trainee progresses in his grasp of the percepts associated with individual task elements, additional cues can be added so that progress through the stage described by Fitts as the fixation stage can be controlled to match the nature of the task to the learning function by which it is mastered.

Since the information making up the digital image scene is stored in software rather than in hardware, it can be programmed for display in any appropriate manner and it can be modified without changing hardware, to optimally support the specific training situation under consideration at a given time.

Table 1 is a summary of the scene elements making up each of the artist's concepts represented in Figures 2 through 7. Table 1 also lists the number of edges used in making up each element and each scene. (Edges are here defined in the way that is now usual – that is, as the edges of polygons which face toward the viewer, whether or not they are occulted by another object, so long as they are within the field of view. Where two edges of an object lie together along their full lengths, they are counted as only one edge.) Each picture represents a pilot's front-window view, and since the most complex scene requires only 2,380 edges, two side windows with normal scene contour could be provided by an 8,000-edge digital image generator. Table 2 is a summary of some of the major task functions supported by each class of scene element.

TABLE 1

POTENTIAL ALLOCATION OF DIG EDGES

FIGURE	SCENE ELEMENT	EDGES	% TOTAL EDGES
2	Ground	4	50
	Runway	4	50
	TOTAL	8	100
3	Ground	4	1.67
	Runway	4	1.67
	Runway Markings	128	53.33
	Taxiways, Cross Runways	32	13.33
	Buildings	72	30.00
	TOTAL	240	100.0
4	Ground (Airport)	15	1.22
	Runway (Main)	4	0.33
	Runway Markings (Main)	144	11.73
	Taxiways, Cross Runway and Markings	56	4.56
	Roads	32	2.61
	Grass Patches and Shadows	62	5.05
	Surrounding Terrain and Hills	165	13.44
	Individual Clouds	30	2.44
	Trees	420	34.20
	Farm Buildings	104	8.47
	Airport Buildings	104	8.47
	Approach Tower	40	3.26
	ILS Shack	52	4.23
	TOTAL	1,228	100.0
5	Ground (Airport)	12	0.50
	Runway (Main)	4	0.17
	Runway Markings	168	7.06
	Taxiways and Cross Runways	56	2.35
	Grass Patches	120	5.04
	Hills	150	6.30
	Individual Clouds	40	1.68
	Trees, Bushes	180	7.56
	Airport Buildings	108	4.54
	Approach Towers	180	7.56
	ILS Shack	72	3.03
	Gravel	1,230	51.68
	TOTAL	2,380	100.0
6	Terrain Scene (Behind Clouds)	1,228	60.26
	Cloud Cover	810	39.74
	TOTAL	2,038	100.0
7	Ground (Airport)	12	0.76
	Runway	4	0.25
	Runway Markings	200	12.63
	Taxiways	40	2.53
	Grass Patches	148	9.35
	Hills	120	7.58
	Individual Clouds	40	2.53
	Trees	45	2.84
	Airport Buildings	208	13.14
	ILS Shack	72	4.55
	Grooves	206	13.01
	Tire Marks, Blemishes	308	19.46
	Runway Edge Lights	180	11.37
	TOTAL	1,583	100.0

5) Illusions. Ritchie (7) has pointed out that illusions can occur in simulator visual systems when minimal cues are presented. An illusory perception occurs when a perceptual conflict occurs among sets of cues to a given situation. Even when each set of cues is individually correct, the absence of cues which are usually present can lead to misinterpretations of some scene elements. The perception of distance in simulator visual scenes is a frequent problem because of the many cues to distance available in the real world. Retinal size, motion parallax, perspective, interposition, surface detail, aerial perspective, and, in some limited cases, accommodation and convergence provide information about range, range rate, time-to-go, and flight path. There is some indication in simulator flying that some cues are more important than others, and that the priority of cues changes with the nature of the task and the maneuver. The deletion of some cues to distance can distort pilot response to those remaining, so that care must be taken in identifying cues which are not only minimally essential, but perceptually consistent. This also must take into account the level of sophistication of the student. Unless he has had an opportunity to exercise control, or to make task-relevant judgements by means of complex visual cues, the deletion of some cues may not be disturbing, or even noticed. The deletion of cues will be most disturbing to the skilled pilot, who may have learned to recognize the effects of his controls on each varying scene element, or on scene elements which are not used by other pilots or instructors as referents. Missing scene elements, unless there is an obvious, task-relevant reason for their absence, inherent in the condition being represented, can produce illusory or abnormal responses. The avoidance of illusions in simulator visual scenes will require analysis and insight with regard to the perceptual and learning problems associated with the tasks being trained. Most illusions appear to result from the inability of the observer to reconcile information that seems to be consistent with the task with other information that seems to conflict with the task. The most disturbing illusions are those in which the observer is not consciously aware of his attention to the source of conflicting information. As a result, great care must be taken in defining the scene elements to which he might be trained to respond, especially in the case of scenes being designed for use in proficiency trainers by skilled personnel.

TABLE 2. EDGE ALLOCATIONS AND THEIR FUNCTIONS IN A DIG LANDING SCENE

FIGURE	SCENE ELEMENT	PILOT TASKS	CUE FUNCTION
2	Ground	Maintain wings level; maintain pitch/power relations for optimum glide angle.	Horizon roll and pitch reference.
2	Runway	Maintain heading alignment; correct wind drift.	Runway shape defines alignment with centerline; shape and location in field of view define wind effects.
		Maintain glide path to runway touchdown point.	Rate of change in shape of runway and in length/width ratio define glideslope angle and touchdown location.
3,4,5, 6,7	Taxiways	Identify aircraft position on approach path in limited and varying visibility; decide to continue or abort approach.	Airfield features provide cues to aircraft location when runway is momentarily obscured.
3,4,5,7	Buildings	Maintain glidepath to runway touchdown point; correct for wind drift.	Relative motion among scene elements provides cues to aircraft position, glide-path, and ground track; changes in build-ing perspective provide cues to altitude.
4,6	Roads	Identify aircraft position on approach in limited and variable visibility; decide to continue or abort approach.	Scene elements surrounding this airfield provide cues to aircraft position when runway is momentarily obscured. Changes in relative position of off-airfield scene elements also provide information about position, flight path, and ground track in normal flight operations, permitting stu-dent to learn to perceive total situation.
5	Gravel	Control glidepath to runway touchdown point.	Surface detail defines terrain configura-tion and nature of terrain surface; relative motion among surface elements helps to define position of aircraft on approach path.
4,5,6,7	Grass Patches and Shadows	Maintain alignment with runway; con-trol glidepath to runway touchdown point.	Changes in apparent shapes and relative motion among terrain surface elements provide cues to aircraft position and to location of touchdown point; off-runway surface details help student to learn to perceive total situation.
4,5,6	Approach Tower	Maintain alignment with runway; control glidepath to runway touchdown point.	Relative motion of top of tower, gravel, and runway surface provides cues to air-craft position on approach path; helps student to learn to perceive total ap-proach and landing situation.
4,5	Individual Clouds	Maintain alignment with runway.	Relative motion between clouds and other scene elements provides cues to aircraft velocity and flight path.
6	Cloud Cover	Recognize aircraft position on approach, in limited and varying visibility; interpret flight status; decide to continue or abort approach.	Visibility effects help the student to learn to interpret minimal cues as they might be available in real-world flight operations.
7	Grooves, Tire Marks	Maintain minimum sink rate at touchdown.	Grooves and individual tire marks provide cues to absolute altitude and altitude rate, supporting practice in adjusting vertical velocity and flare height within acceptable limits.
		Control heading during rollout; reduce velocity to permit turn to taxiway.	Tire marks and blemishes provide cues to ground velocity used in predicting and controlling effects of rudder, brakes, re-verse thrust in slowing to taxi speed, and in executing ground turns.
4,5,7	Hills	Maintain runway alignment during land-ing rollout; make smooth turns from driveway to taxiway.	Hills and other distant objects provide cues to heading, whose effectiveness is proportional to their distance from the pilot's point of view.

Ultimately, experimentation will be required in the prediction of potential problems in the inadvertent production of illusory responses to simulated visual scenes. Insights can be gained, however, through the careful investigation of operator responses in a variety of real-world situations. Most experienced pilots, for example, can recall operating with minimal visual information, or with different information than is normally available. These experiences are valuable sources of data concerning pilot response to scene elements which are ordinarily ignored, and thus not directly accessible at the verbal level. A great deal of information can also be obtained from experience with existing simulator visual systems, expecially when they do not represent some cues as well as is needed. Helicopter pilots, for example, have recently experienced problems in hovering at a prescribed altitude in the simulator. The problem seems to be the size of textural elements in the ground scene.

6) Capabilities of Digital Image Generators in Training. During the fixation phase of learning, the student needs to be able to develop discrete responses to discrete cues, to the extent possible. This phase provides him with a repertory of stimulus-response relationships which, ultimately, permit elementary responses to be made to the variety of cue patterns encountered in training. It also permits differential responses to be made to cue patterns which at first seemed identical. Practice reduces the amount of cognition (and time) required in identifying the response needed at a given time and, in the presence of a workload, establishes techniques for the time-sharing and phasing of task elements.

Relevant visual scene elements are essential in the development of an effective response repertory, along with some way of fixating correct responses to these scene elements. Normally, in both flight and simulator training, stimulus-response relationships are fixed through the action of rewards intrinsic to the task, as defined in the performance criteria associated with it. All training programs, at some time, employ artificial rewards to facilitate learning, in addition to those inherent in the task itself. DIG systems are especially capable in this area, permitting visual feedback to be programmed as appropriate.

Students who have half passed through the fixation stage and who have already automated many task skills can also profit from the flexibility of digital image generation systems. The skilled pilot's learning task bears one important surprising similarity to that of the novice: he too must learn to recognize differences among similar patterns of stimuli so that he can predict and execute responses appropriate to these differences. The DIG's capability is still limited in providing visual cues to the subtle differences in terrain, vegetation, and target images required in completely skilled operations, but it can portray relatively distinct differences among similar conditions within mission-like task contexts. These complex task environments can provide skilled pilots with opportunities not otherwise available for the refinement of task response dynamics. The edge capability of most DIG systems also permits the incorporation of enough visual cues to simulate realistic pilot workloads to support practice in time-sharing and in the division of attention frequently required in operational flight systems.

Artificial feedback may also be important in facilitating the refinement of skilled performances, but very little information is available to indicate the most relevant types of feedback, or the most effective feedback algorithms appropriate to proficiency maintenance. DIG system flexibility will permit experimentation in the enhancement of learning and performance improvements in proficiency training as well as in the training of novices. In both extremes of the training continuum, digital image generation systems can enhance the training value of simulators by requiring the definition of scene content and visual scene dynamics in terms of learning functions rather than realism.

7) Data Base Design for Training. By far the most important consideration in the design of visual cuing systems is the systematic development of scenes and scene elements relevant to the specific learning task at hand. Tasks to be learned almost always consist of multiple task elements, and most learning functions change with learning. Each of these facts makes unique and specific demands on the content and arrangement of the stimuli provided for training. We would suggest, then, the following sequence of activities for the design of digital image data bases for training:

First, a set of scene elements, tasks, and functions similar to those shown in Table 2 should be compiled by psychologists who have studied the problem.

Second, a team consisting of an artist and an engineer intimately familiar with the capabilities and limitation of the digital image generator should work together to create renderings similar to those of Figures 4 through 7, for instance, tabulating the edges used and their percentage as in Table 1. We have found that after some experience in this, the artist will be able to come very close to what the psychologist and the engineer are willing to accept from their respective viewpoints, on the very first attempt.

Third, the renderings and the tables should be made available to the data base design group, which should contain people who can draw the various cultural and special objects as orthographic drawings, and people who know how to digitize these drawings using interactive computer equipment that creates the data base. The data base design group should be led by engineers who pay attention to the careful balancing of edge capacities, intersection limits, moving objects, special effects, the allocation of edges to various versions of objects as they are viewed at various ranges, retrieval problems, and overload problems. Their goal, however, should be to match the general design determined in the initial steps and related directly to the training problem.

CONCLUSION

Digital image generation systems provide training device designers with a unique challenge: since they cannot provide any visual scene content until they are programmed, they demand detailed scene designs and design rationales. Previous systems were as "real" as the scale of the model, or the size of the film, would permit, including some unique cues, some irrelevant cues, and some inadvertent distortions of otherwise relevant cues. With care, digital systems can provide exactly those cues required for optimum learning and transfer. The primary requirement is for careful analysis of visual cue involvement in the tasks and task elements to be trained, and precise definition of the learning processes involved.

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CIG EDGE CONSERVATION EVALUATION AND APPLICATION TO VISUAL FLIGHT SIMULATION

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INTRODUCTION

This paper addresses a new approach to the visual scene presentation within a wide-angle optical mosaic display of computer-generated imagery, and a means of determining and analyzing the visual system processing and display capacities being utilized. An area of interest (AOI) presentation concentrates visual detail in that portion of the entire display to which the pilot's immediate attention is directed. The AOI transverses the display in real-time in coordination with the movement of the pilot's head. The result is a more efficient and effective utilization of system processing capacities which can be measured with the system's visual parameter monitor (VPM). An operational description of the VPM and AOI, together with an example of their integrated application, constitutes the body of this report.

VISUAL PARAMETER MONITOR (VPM) DESCRIPTION

Computer Image Generation systems are relatively new in the simulation technology; and, therefore, a data bank of information needs to be compiled that would be useful for generating training and engineering specifications that will satisfy user requirements. Theoretically, the training requirement should drive the general systems specifications (for example, field-of-view requirements should be based on a specific training task for a given aircraft). The engineering specifications should then optimize the parameters that limit and/or define the visual processing potential of the system. The Visual Parameter Monitor (VPM) feature of the Advanced Simulator for Pilot Training (ASPT) provides a tool for both training researcher and engineer to investigate the Computer Image Generation (CIG) system hardware and hardware limiting parameters. The VPM can be applied in several CIG functional areas. Applications include an ability to conduct environment data base statistical analyses, experimental configuration definition, maintenance troubleshooting, real-time performance monitoring, and more accurate specification of future CIG system requirements. These functional areas can be categorized under two basic modes of CIG system operation: off-line and on-line. Real-time scene generation is accomplished in the on-line operational mode. Data base management operations and maintenance diagnostic operations are performed in the off-line operational mode.

In the on-line operational mode, the system accomplishes its real-time scene generation task in a serial computational manner. Data necessary to compute each scene is requested from the simulator computer each 1/30 second, and the corresponding scene is displayed approximately three television frame times (3/30 second) from the time of receiving new or extrapolated scene data. The CIG system is configured into three major equipment areas: The General Purpose (GP) computational system, the Special Purpose (SP) computational system, and the CRT electronics (Figure 1). Three time frames are utilized for processing the display data. The time phases are associated with the 33 millisecond frame time in which the data is processed in response to an updated viewpoint position and attitude. The equipment that performs these three time-phased tasks is referred to as Frame I, Frame II, and Frame III, respectively. While the Frame III hardware is producing the video signal which is used to present the picture being observed, Frame II is preparing information to be used for the picture to follow in the next television time frame period, and Frame I is working on data for the frame to follow that (Figure 2). Frame I operations are performed by the CIG system's GP dual-processor computer complex. During the first 33 milliseconds, this computer requests data from the simulator computer and performs frame rate processing functions necessary to generate data for the special-purpose hardware. The GP computer then processes these inputs to generate necessary data for Frame II operations and any output messages required to the maintenance console.

The following Frame I parameters are monitored by VPM:

- ACTIVE OBJECT COUNT
- POTENTIALLY ACTIVE OBJECT COUNT
- NUMBER OF ACTIVE MODELS
- NUMBER OF MODELS CHANGING PER FRAME TIME
- NUMBER OF LEVEL OF DETAIL CHANGES PER UNIT TIME
- NUMBER OF NEW MODELS TO BE ADDED TO ACTIVE ENVIRONMENTS/FRAME TIME
- DEPTH OF QUEUE OF NEW MODELS/ FRAME TIME
- NUMBER OF MODELS THAT GO TO LEVEL OF DETAIL
- NUMBER OF FACES INTO FRAME II
- NUMBER OF OBJECTS PER CHANNEL

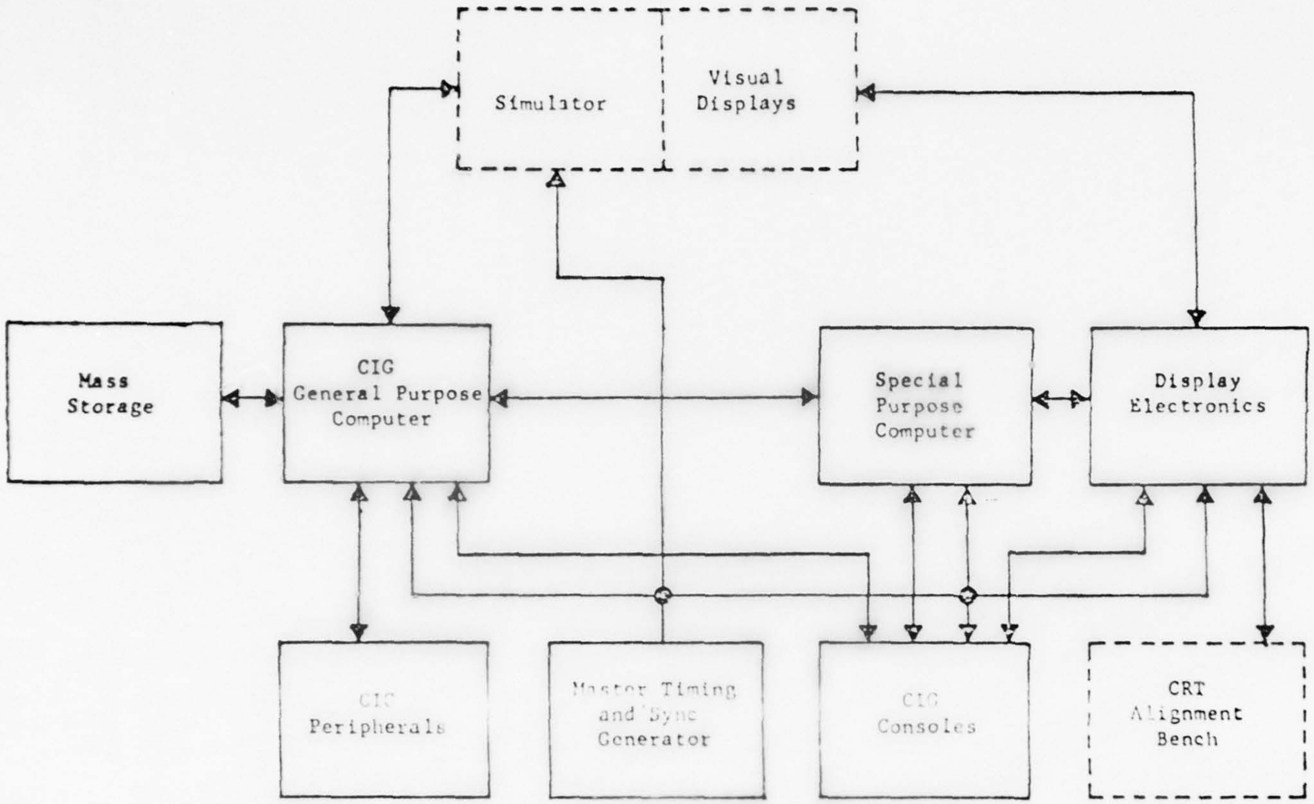

Figure 1. Computer Image Generation System

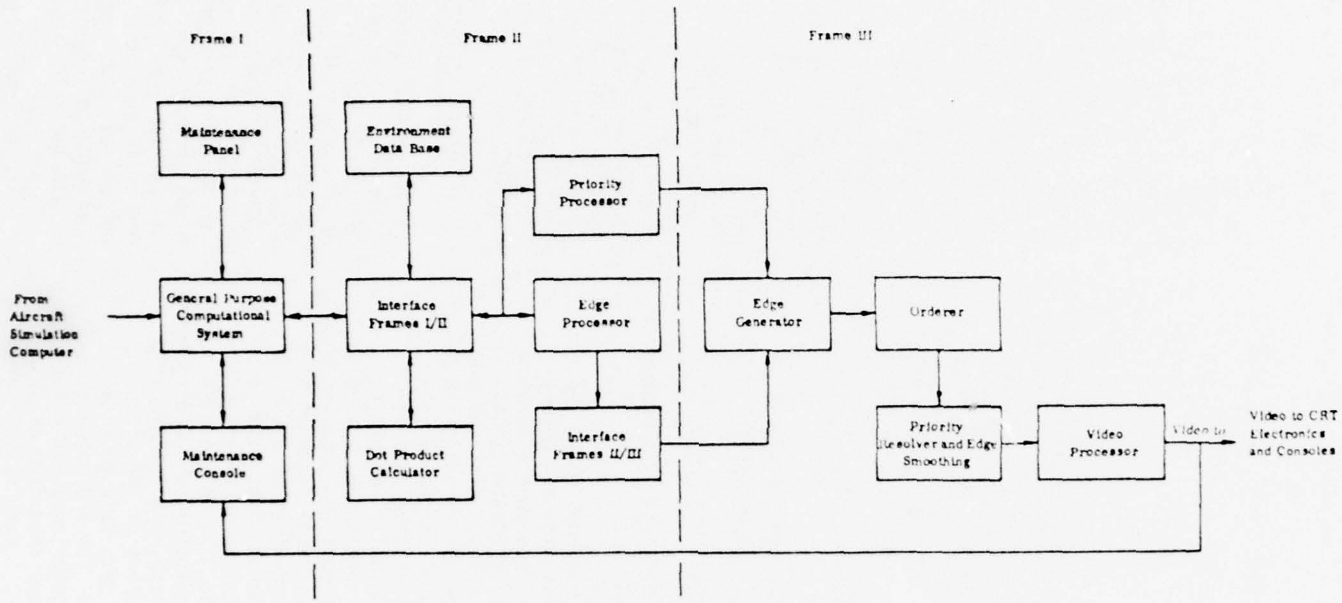

Figure 2. ASPT CIG System Functional Diagram

The calculation of the required edge and grey shade information is performed by the Frame II hardware. The major functions of this equipment are edge processing, fading and light brightness corrections, vector transformations, and priority processing.

The following Frame II parameters that are monitored include:

- FRAME II TOTAL EDGE COUNT (INTO EDGE PROCESSOR)
- FRAME III TOTAL EDGE COUNT (OUT OF EDGE PROCESSOR TO FRAME III)
- NUMBER OF ACTIVE FACES
- NUMBER OF EDGES/CHANNEL/FRAME

The Frame III hardware creates the video signals for the display projector by successively processing and accumulating data for each raster scan line. The data is accumulated for each raster scan line of each of the display channels, and then converted to video output signals. The major portions of the Frame III hardware are edge storage/edge generators, video/video storage, priority resolvers and video processors. The Frame III parameters that are monitored in real-time are:

- MAX EDGE CROSSINGS/SCAN LINE/FRAME
- NUMBER OF OBJECTS IN PRIORITY CONFLICT
- MAX NUMBER OF EDGE CROSSINGS/LINE/SYSTEM
- NUMBER OF EDGE CROSSINGS PER CHANNEL PER SELECTED LINE

In the off-line operational mode, the system performs data base and maintenance diagnostic operations. Data base diagnosis entails the debugging of operational data bases for training exercises. With the VPM, much of the trial and error procedure can be removed from the data base diagnostic sequence. The environmental data base for a CIG visual system is basically defined by straight line segments referred to as "edges." These straight line segments are combined to form two and three dimensional features of the environment. The organization and complexity of the environmental data base is constrained by CIG system hardware and software limiting parameters. It is essential that in specifying, developing, and modifying an environmental data base, the relationship between limiting parameters of the visual system and the desired data base be made available for analysis. The VPM provides a systematic means of categorizing and cataloging visual scenes generated from existing environmental data bases. Each visual scene cataloged can be recorded photographically and will include the extremes and statistics for each key system parameter. The software provides capabilities for both man-in-the-loop and preprogrammed control of the flight pattern through the environment and allows the experimenter to preprogram the statistical parameters and values which will automatically stop the viewpoint motion to provide a visual scene freeze. A printout of a complete set of statistics for the frozen visual scene can then be provided by an operator command.

Catalogs can be developed which will logically categorize and catalog mission representative visual scenes from any environment. Individual catalogs would consist mainly of photographs accompanied by parameter statistics and descriptive information indicating the viewpoint, location, and attitude within the environment. Investigations with VPM would provide a means to analyze the relative and absolute relationships between the various CIG system limiting parameters as they relate to typical environmental data bases. This information would be extremely beneficial for specifying any CIG systems and their associated data base requirements.

Interaction with CIG parameter processing, both on-line and off-line, is via a continuous display on a high-speed, interactive display terminal CRT. This display is provided on an Infoton Vistar/GTX Display Terminal and permits the operator to select parameters with the terminal keyboard. Under keyboard control, the operator has the option of reading certain CIG limiting parameters or any special-purpose computer data bus quantities. Standard displays would include all or a selected subset of the Frame I, II, and III parameters previously listed. In addition to the CRT output, other mediums, such as the line printer, are available to the user of the VPM.

AREA-OF-INTEREST DESCRIPTION

An area-of-interest projection in a wide-angle field-of-view (FOV) display in its pure form would present visual scene information only in the portion of the display in which the pilot is looking. The size of the AOI may vary, depending upon the application. For some applications, such as air-to-surface weapons delivery, certain visual information is necessary throughout the display. In cases such as this, a compromise can be made. Visual reference cues such as horizon and surface texture can be provided as peripheral cues throughout the display, whereas detailed visual information would only be displayed in the AOI.

The implementation of an AOI display for the ASPT was performed in a number of steps. The first step was to generate a number of fixed-size hoods to occlude the visual scene laying outside the desired FOV. (Figure 3)

These hoods were generated as the moving model of the environmental data base which was fixed to the viewpoint, aligned parallel to the longitudinal axis of the simulator aircraft and flew the same flight path. The next step was to generate computer software capable of creating a hood with any desired FOV in real-time via operator interaction. At this point, the data base features obscured by the hood were still being processed by the computer but were not seen in the display, since the hood had priority over all other objects. (Figure 4) It was now desirable to eliminate from processing those objects which did not intersect the FOV, in order to permit the concentration of objects and edges within the AOI. The hood, however, was still necessary to occlude the portion of a displayed object laying outside the AOI. The ideal situation would have been to eliminate the hood and truncate an object at the AOI boundaries; however, this would have involved hardware modifications requiring excessive lead time. Since an evaluation of the AOI concept had a pressing deadline, it was decided to postpone the incorporation of this refinement. Hardware and software modifications were also made at this time to make the hood independent of the environmental moving model and enable the AOI to be slewed throughout the cockpit display in real-time. Provision was then made to incorporate a helmet slaving device (HSD) in one of the simulator cockpits. (See Figures 5 and 6.) This system consists of a helmet with a pair of infrared sensors mounted on both sides, two sensor-surveying units, sight control unit and a control panel. Two sensor-surveying units are hard-mounted to the cockpit on each side and slightly to the rear of the pilot. These units generate infrared light beams which trigger signal pulses when they sweep over the helmet detectors. The sight control unit contains the digital circuitry for converting the detector pulse signals from the helmet sensors and sensor-surveying units into digital angles, and converting these angles into azimuth and elevation signals for controlling the line of sight of the AOI. Preliminary test operations indicated that a smooth, continuous movement of the hood without any jitter could be obtained with 0.5 degree filtering. Pilots also observed that it was extremely difficult to maintain their orientation without a horizon throughout the display. It was found that redefining the hood as a two-dimensional object allowed the horizon to have priority over the hood, with the hood still having priority over all other objects. Figure 7 exhibits this feature.

This configuration was used in an evaluation conducted in support of ASD/SD24 Simulator SPO Project 2360, Fighter/Attack Visual Simulation. The major objective of this evaluation was to determine the size of the AOI required, in order to adequately perform air-to-surface weapons delivery. A second phase of this study is planned to evaluate the effect that peripheral cues (in addition to the horizon) will have on the size AOI required for adequate air-to-surface weapons delivery performance. Engineering modifications will be performed to permit operation in this phase without a hood and yet retain distinct boundaries of the AOI through the truncation of the portion of an object extraneous to the AOI. The peripheral cues would, of course, be shown throughout the display.

AN AOI APPLICATION

The basic premise for an AOI presentation in a wide-angle FOV-CIG display is to conserve system edge processing capacity by displaying more visual data base edges in the area to which the pilot's attention is directed, at the sacrifice of displaying fewer edges in the periphery. This results in a more efficient utilization of the system edge processing capacity and conserves resources by requiring less computer processing hardware than would be required by a full FOV display for a data base of given edge density. In other words, a system having a given edge processing capacity which could display a data base of given edge density with the full wide-angle FOV display could display a more detailed or denser data base with an AOI display. Since the density of the displayable data base is inversely proportional to the size of the AOI and the CIG system's costs are directly proportional to system edge capacity, considerable cost savings could be achieved utilizing this approach.

To effectively determine the efficiency of an AOI application, a means to measure the CIG visual system parameters for various configurations is required in order to make the necessary comparisons. The VPM, as previously described, provides a valuable tool for such a comprehensive investigation. Figures 8 and 9 are photographs taken from the exact same viewpoint (with two different size AOI's) of a CIG scene of two different edge densities. They serve to illustrate the potential application of the AOI and VPM concepts. Tables 1 and 2 list the counts for some of the CIG visual system parameters for Figures 8 and 9, respectively.

The AOI size for Figure 8 is 70° horizontal by 50° vertical, whereas Figure 9 has an AOI size of 50° horizontal by 30° vertical. As can be observed from the figures and tables, the scene in Figure 9 is denser than the scene in Figure 8. The AOI size for Figure 9 is less than half that of Figure 8 and its scene contains 1.7 times as many edges. Since the purpose of this paper is

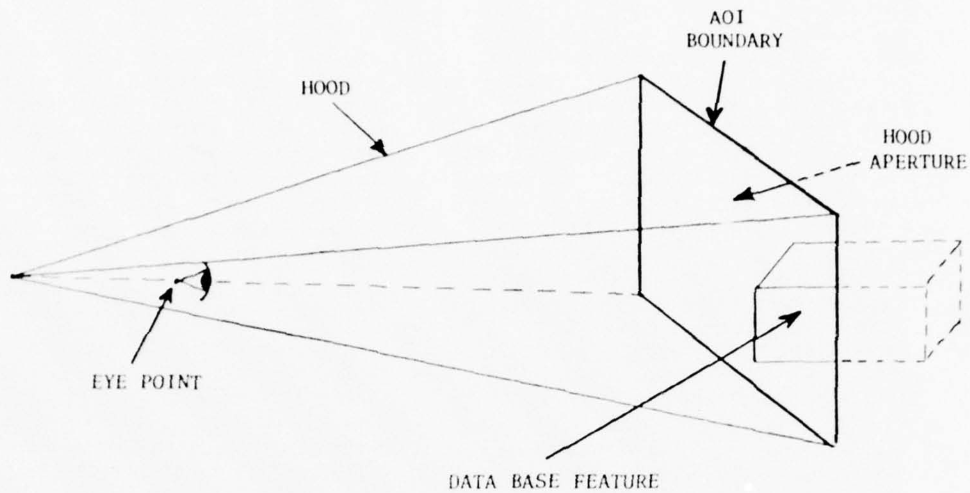

Figure 3. AOI Hood

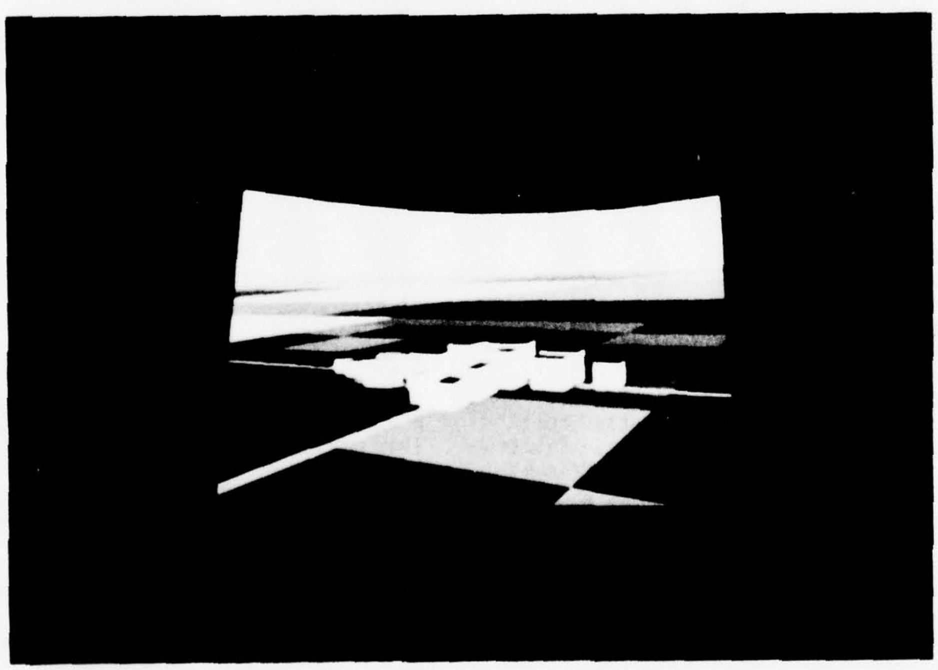

Figure 4. AOI Presentation with Hood

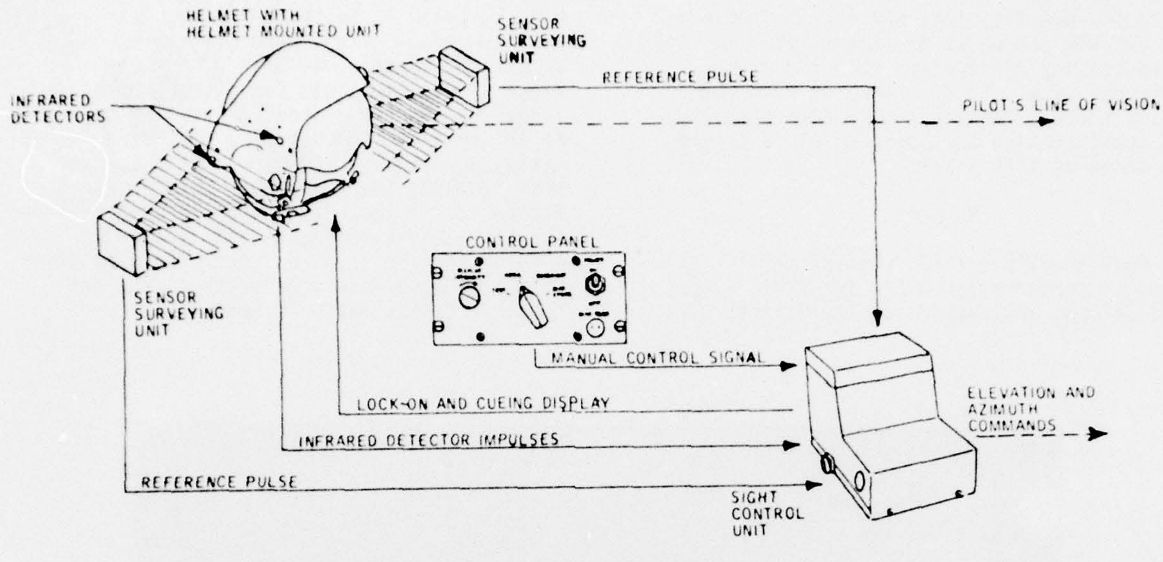

Figure 5. Helmet Slaving Device System

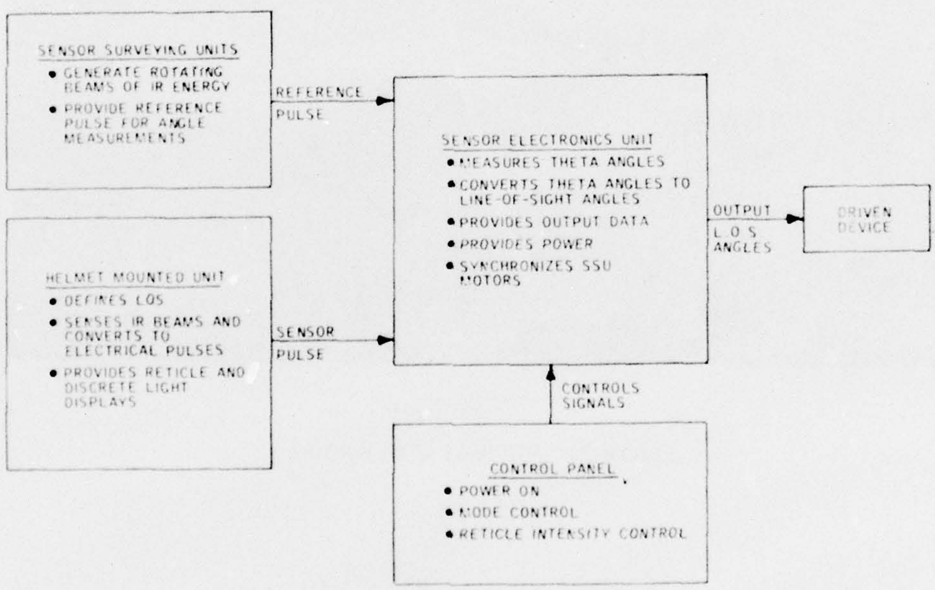

Figure 6. HSD Block Diagram

merely to acquaint the reader with the potential benefits that may accrue from the AOI and VPM concepts, no attempt will be made to derive any conclusions from the aforementioned data. To generate any such conclusions would require a much more detailed and sophisticated analysis, which is beyond the scope of this paper.

SUMMARY

Both the VPM and AOI present considerable resource conservation tools for CIG systems applications and design considerations. The AOI concept provides a technique whereby the visual system capacity can be more efficiently utilized by dynamically concentrating image detail in the critical area of the display. Since CIG system costs are directly proportional to the system edge generation capacity, an AOI presentation offers a considerable cost saving potential. The VPM is a unique tool that provides the researcher with an exact definition of the visual systems configuration for any given experiment. It allows the modeler and the engineer access to parameters that influence data base requirements and special-purpose hardware designs.

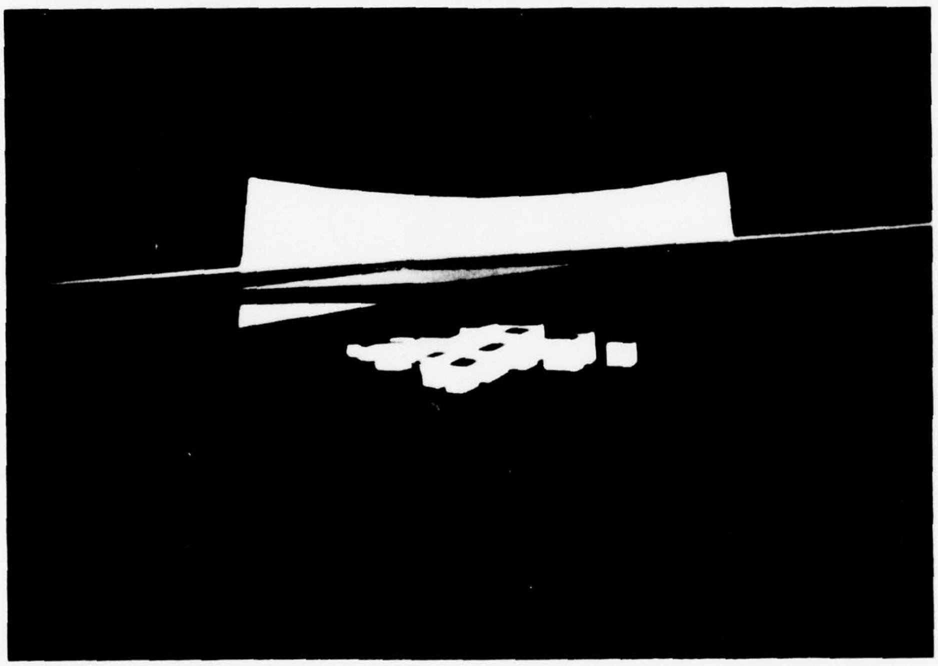

Figure 7. AOI Hood with Horizon

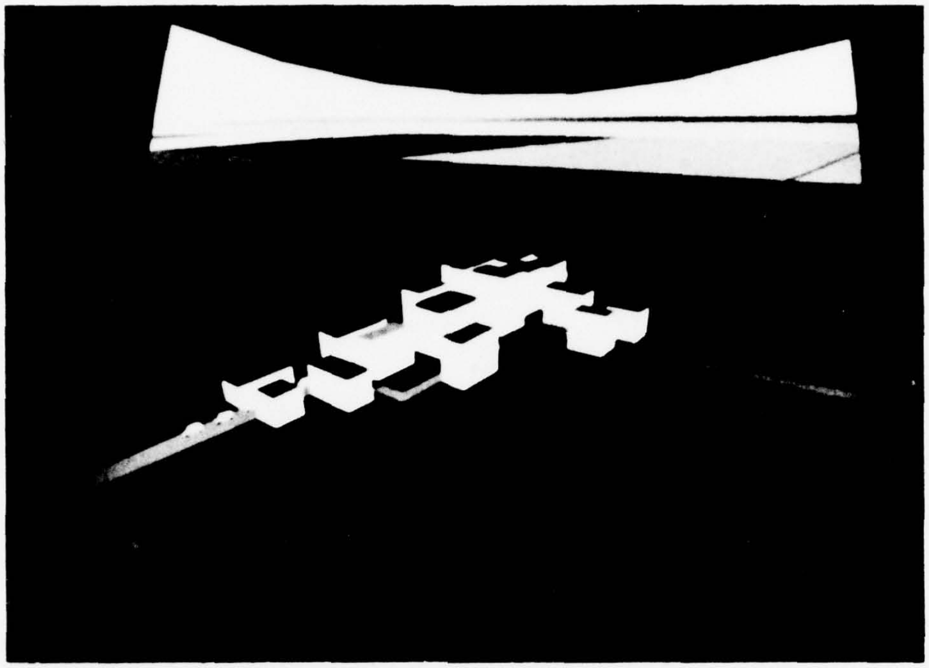

Figure 8. AOI Display (70^{0} x 50^{0})

TABLE 1. VPM COUNTS FOR FIGURE 8

Potentially Active Models	64
Active Models	31
Potentially Active Objects	114
Active Objects	63
Frame II Edges	1991
Frame III Edges (Potentially Visible)	667

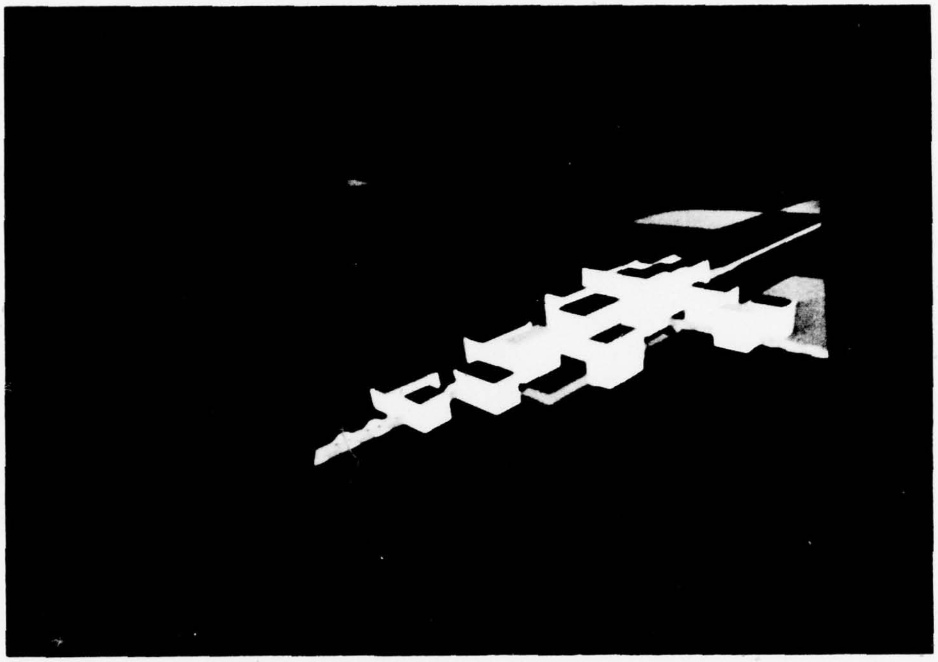

Figure 9. AOI Display ($50^0 \times 30^0$)

TABLE 2. VPM COUNTS FOR FIGURE 9

Potentially Active Models	66
Active Models	33
Potentially Active Objects	129
Active Objects	78
Frame II Edges	3236
Frame III Edges (Potentially Visible)	1134

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LABORATORY DEMONSTRATION OF COMPUTER SPEECH RECOGNITION IN TRAINING

ROBERT BREAUX
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INTRODUCTION

Background

The Naval Training Equipment Center's Human Factors Laboratory seeks to identify and measure those behaviors which, when improved through training, result in superior performance on the job. Thus, the laboratory seeks to combine new technology developments with current advances in learning/training theory and techniques.

One such technology development is computer speech recognition. The advantage brought to training by this technology is the capability to objectively measure speech behavior. Now, traditional training techniques for jobs which are primarily speech in nature require someone who can listen to what is being said. Otherwise, no measure of the speech behavior is possible. In the U. S. Navy, jobs which are primarily speech in nature include the Ground Controlled Approach (GCA) and Air Intercept (AIC) controllers, as well as the Landing Signal Officer for carrier operations, various Naval Flight Officer positions such as the Radar Intercept Officer, and the Officer of the Deck in ships operations. In addition to the requirement of having an instructor listen to the speech behavior, training in these situations often requires another person to cause changes in the environment which correspond to the trainee's commands. For the GCA and AIC tasks, this takes the form of "pseudo" pilots who "fly" a simulated aircraft target. This 2:1 ratio of support personnel to trainee results in a relatively high training cost.

Previous studies have demonstrated that in analogous situations, it has been possible to achieve savings of manpower and training time while gaining a uniform, high-quality student output by introducing automated adaptive instruction. This advanced technology, if applied to GCA controller training, would bring in its standard benefits such as objective performance measurement and complete individualized instruction. Moreover, for GCA controller students, a more fully automated system could provide greater realism in the performance of "aircraft" under control by accessing directly the computer model of aircraft dynamics rather than relying on the undetermined skills of a variety of pseudo-pilots. Additionally, the rapid processing of an automated system would make possible extrinsic feedback of task performance to the trainee in real-time.

But in order to realize an automated adaptive training system, it is essential that, in addition to values of overall system performance, some relevant aspect of the trainee's activity, in this case his speech behavior, be accessible to the performance measurement subsystem. At this point, our technology review suggested that the state of the art in machine understanding of speech could furnish the means for direct entry of a trainee's advisories. For some whose acquaintance with this possibility is limited to the science fiction of film, television and print media, the response might be "Of course! Why not?" Those more familiar with the problem might say, "Not yet!" The reality is that while computer understanding of continuous unrestricted speech, without pretraining, by any individual who approaches, is still a long way off, there exists today a capability for machine recognition of isolated utterances drawn from a small set of possible phrases. The computer in this case must be pre-trained on the language set with speech samples for each individual speaker.

Automated Adaptive Instruction

Automated adaptive training has a number of advantages over the more traditional approaches to training. Automation of training relieves the instructor of busywork chores such as equipment setup and bookkeeping. He is thus free to use his time counseling students in his role as training manager. In adding the adaptive component, efficiency is increased with more training per unit time. Individualized instruction, with its self-paced nature maintains the motivation of the trainee. Objective scoring is potentially more consistent than subjective ratings. Uniformity can be maintained in the proficiency level of the end product, the trainee. But, tasks requiring verbal commands have thus far been unamenable to automated adaptive training techniques. Traditionally, performance measurement of verbal commands has required subjective ratings. This has effectively eliminated the potential development of individualized, automated, self-paced curricula for the training of the aforementioned Landing Signal Officer, the Air Intercept Controller, the Ground Controlled Approach Controller, and others. Computer speech recognition of human speech offers an alternative to subject performance measurement by providing a basis of objectively evaluating verbal commands. The current state of the art has allowed such applications as automated baggage handling at Chicago's O'Hare airport. A more sophisticated recognition system is required for training,

however. To that end, the Naval Air Systems Command and the Advanced Research Projects Agency have supported the Naval Training Equipment Center Human Factors Laboratory in efforts to establish design guidelines for training systems which combine automated adaptive training technologies with computer speech recognition technology. The particular application chosen is the Precision Approach Radar (PAR) phase of the GCA.

TRAINING REQUIREMENTS

The GCA Application

The task of the GCA Controller is to issue advisories to aircraft on the basis of information from a radar indicator containing both azimuth (course) and elevation (glidepath) capabilities. The aircraft target projected on the elevation portion of the indicator is mentally divided into sections by the controller. This is because the radio terminology (R/T) for glidepath is defined in terms of these sections. Thus, at any one point in time, one and only one advisory is correct. Conversely, each advisory means one thing and only one thing. This tightly defined R/T is perfect for application of objective performance measurement. The drawback, of course, is that performance is verbal and has thus far required subjective ratings. In addition, the time required for human judgment results in inefficient performance measurement. The instructor cannot catch all the mistakes when there are many.

Needs and Objectives

The major behavioral objective of current GCA training is to develop the skill to observe the trend of a target and correctly anticipate the corrections needed to provide a safe approach. The standard R/T is designed to provide a medium to carry out this objective, and GCA training exposes the student to as many approaches as possible so that the trainee may develop a high level of fluency with his R/T.

The primary need to fulfill its objective is for GCA training to teach the skill of extrapolation. A controller must recognize as quickly as possible what the pilot's skill is. He must recognize what the wind is doing to the aircraft heading. Then he must integrate this with the type aircraft to determine what advisories to issue.

Advanced Technology

The major behavioral objectives, then, can more efficiently be achieved through the application of computer speech recognition technology, and thereby the application of advanced training technologies. This is because with objective assessment of what the controller is saying, objective performance measurement is possible, and thus we have the capability of individualized instruction. The use of simulated environmental conditions allows the development of a syllabus of graduated conceptual complexity. The integration of these components results in an automated, self-paced, individualized, adaptive training system.

The job of the instructor now becomes one of training manager. His experience and skill may be exploited to its fullest. The training system can provide support in introducing the student to the R/T. The instructor can scan the progress of each student and provide counseling to those who need it. Simple error feedback is provided by the training system. Only the instructor can provide human to human counseling for specific needs, and the training system provides more time for this valuable counseling.

TRAINING SYSTEM OVERVIEW

A training system for the GCA comptroller was determined to require four subsystems, speech understanding, pilot-aircraft model, performance measurement, and a syllabus. The speech understanding subsystem was developed around the VIP-100 purchased by the Naval Training Equipment Center from Threshold, Inc., Cinnaminson, New Jersey.

Three major constraints are imposed by this system. Each user must pre-train the phrases. Recognition does not take place for random, individual words, only predefined phrases. Each phrase is repeated a number of times and a Reference Array is formed representing the "average" way this speaker voices this particular phrase. Thus, the second constraint is that there must be a small number of phrases (about 50) which are to be recognized. If performance is to be evaluated based upon proper R/T, each phrase must be defined. The third constraint, due to performance measurement requirements, is that there be no ambiguous phrases -- right or wrong depending strictly on who the instructor is. Technically, the GCA application appears to be conformable to these constraints.

To achieve high fidelity, simulation makes use of various math models: The model of the controller is at the focal point of all other models, and serves to provide criteria to the performance measurement system. A model of the aircraft and pilot allows for variation in the complexity of situations presented the student. The principle being used here is that exposure of a student to certain typical situations will allow him to generalize this experience to real world situations. The pilot model allows for systematic presentation of various skill levels

of pilots. In addition, the equations used in modeling the pilot and aircraft responses also allow for introduction of various wind components. The adaptive variables, pilot skill, aircraft characteristics, and wind components are combined systematically to produce a syllabus graduated in problem complexity. As the skill of the trainee increases, he is allowed to attempt more complex problems.

Since the score is determined by the performance measurement system, the heart of scoring is the model controller. As it often happens, what constitutes "the" model controller is a matter of some discussion among GCA instructors. Thus for automated training applications, one must determine the concepts which are definable, such as how to compute a turn, and leave other concepts to be developed by the instructor-student apprentice relationship.

RESULTS

The Problem of Novelty

In an attempt to verify the recognition algorithms, naive adult males were employed as subjects. It was soon discovered that probability of correct recognition was as low as 50 percent in the beginning and phrases had to be retrained to increase recognition reliability. It was hypothesized that the novelty of "talking to a machine" was a significant factor in the low-recognition reliability. If this initial novelty could be reduced, it was thought, reliability would also increase. Four adult males and four adult females were used to compare an introduction method vs a no introduction method. The introduction group was given R/T practice, saying the GCA phrases as they would later in an actual prompted run. The model controller was utilized to anticipate for the subject an optimum response every four seconds. This prompt was presented graphically on the display, as the aircraft made the approach. The subject spoke the phrase, then both the prompt and the understood phrase were saved for later printout. The no introduction group on the other hand, was not given practice. Each group then made reference phrases. Reliability data was collected using the procedure described above for R/T practice. A Chi-square value was computed from a 2 x 2 contingency table of frequency of runs in which no recognition errors occurred vs frequency in which one or more errors occurred, and whether there had been practice on the phrases vs no practice prior to making the voice reference patterns. It was found that $\chi^2(1) = 3.12$, $p < .10$ indicating a relationship. A correlation was computed for the groups vs the number of different phrases which were not recognized on a run, with $R = -.33$, $p < .10$, indicating a tendency for fewer errors with pre-practice at the task. Conclusion: Better recognition is achieved when the R/T is voiced consistently and unemotionally.

Training System Evaluation

Twelve recruits were used from the Recruit Training Command, Orlando, who were in their last few weeks and, therefore, were privileged with liberty on the weekend. Each had received assignment to the Navy's Air Traffic Control (ATC) School. Each subject was interviewed for willingness to participate in an "experiment" during liberty hours concerning ATC, and each was informed that for their time they would be paid. Each subject expressed a desire to become an air controlman.

Each subject was issued at the interview those portions of the programmed instruction booklets normally used by the ATC School relating to the Precision Approach Radar (PAR) phase of GCA, and was requested to complete the material prior to arrival at the lab. Each subject was exposed in the lab to approximately three hours of "introduction." During this time the system collected and validated the voice pattern of the subject for each of the PAR phrases. During the between-run intervals, audio recordings were played which explained and reviewed the PAR R/T. Recognition accuracy by the system on the final run of each subject ranged from 81.5% correct to 98.5% with an average of 94.1% correct recognition.

Subjects were then exposed to "free" runs in which they had complete control over the aircraft. It was found that recognition accuracy suffered during the first few runs. The change from a system which fully prompted the subject on the R/T to a full scoring system which required the subject to initiate all R/T, resulted in a noticeable change in the voicings of the R/T. Hesitation, repetition, and corrections were made which, of course, is not within the capability of the speech system to accurately recognize. R/T voicing improved with practice, however.

Subsequent School Evaluation

The ATC School was informed of which persons had been exposed to the lab PAR system. Eight of the original 12 subjects completed the 14 week school. Four dropped for "various academic and nonacademic" reasons, and were therefore dropped from further analysis. During school PAR training which followed exposure to the lab system by about 14 weeks, the subjects' average performance was equal to the school average. A product moment correlation was computed for final score at the school vs complexity level achieved on the lab system. The positive correlation ($R = .78$, $p < .05$) indicates that better performance on the lab system was related to higher scores at the school. School instructors reported better than average voicings of the R/T by the subjects exposed to the lab PAR system.

The conclusion drawn was that the lab PAR system taught skills similar to those required at the ATC school and, further, that the use of computer speech recognition can be combined with advanced automated training technology to produce an automated training system for the PAR portion of GCA training. Procurement is underway for an experiment prototype system to be installed and evaluated at the ATC school itself.

SUMMARY

A system was described which provided a laboratory evaluation of the feasibility of the use of computer speech recognition in training. Results of the evaluation indicate that training can be enhanced and manpower costs reduced by a careful integration of advanced training technology with off-the-shelf computer speech recognition hardware which is enhanced with software algorithms designed for a specific vocabulary set. The need was indicated for further research and development via an experimental prototype system to be installed at the Navy's Air Traffic Control School.

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FIBER OPTICS FOR TRAINER
APPLICATIONS

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ABSTRACT

A new era is upon us; down with copper wire cable proliferation (Figure 1); the age of cool bright optical communications is here. Presently, there are large performance advantages (bandwidth, noise immunity, signal attenuation, size, weight, and total electrical isolation) associated with fiber optics data communications. In the very near future, there will also be cost advantages.

This paper gives an introduction to fiber optics and shows how to apply this exciting technology to trainers for RESOURCE CONSERVATION THROUGH SIMULATION.

INTRODUCTION

In recent years, fiber optics technology has become a very promising candidate to replace metallic wire conductors. The stimuli for this advancement are the recent reduction of signal attenuation of fiber optics and the rapid advances in semiconductor light sources and photodetectors. This paper will introduce fiber optics technology and describe trainer applications.

Recent predictions on fiber optics show that they will provide the largest growth area in electronics since the integrated circuit. It is hoped that this paper will serve to stimulate systems' users and designers to consider the potential advantages of fiber optics and to evaluate this technology as it applies to their systems requirements.

The following developments are taking place in the fiber optic field:

1. All telephone interswitching center communications of under five kilometers are being converted to fiber optics.

2. Cable TV systems in the U.S., England, Germany, and Japan are using fiber optics.

3. The Navy has two ships at sea with fiber optic systems.

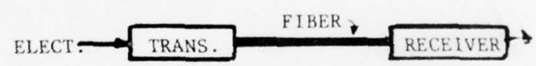
4. The Navy converted and flew an A7E aircraft with fiber optic fire control system with the following results:

	WIRE	FIBER OPTICS
No. of Cables	302	13
Total Length	4832 Ft.	260 Ft.
Cable & Connector Weight	87 lbs.	3.6 lbs.
Parts Cost	9.7 K	1.1 K

FIBER OPTIC JARGON

The following fiber optic terms will be used throughout the paper:

1. TYPICAL F/O SYSTEM



A typical fiber optic system consists of three elements:

(a) A transmitter that converts the electrical signals into light energy signals. The antenna or energy projection device is usually a LED or Laser Diode (Gallium Arsenide Technology).

(b) The fiber light guide that carries the optical energy.

(c) A receiver that converts the light energy signal into a useful electrical signal. The detector or energy absorption device is usually a PIN diode or Avalanche detector (silicon technology).

2. FIBER CABLE

The principle of transmitting light energy requires that the light stay within the fiber cable (waveguide). This is accomplished by having the index of refraction different between the center and outside of the cable (total internal reflection). When the inside tube contains one index

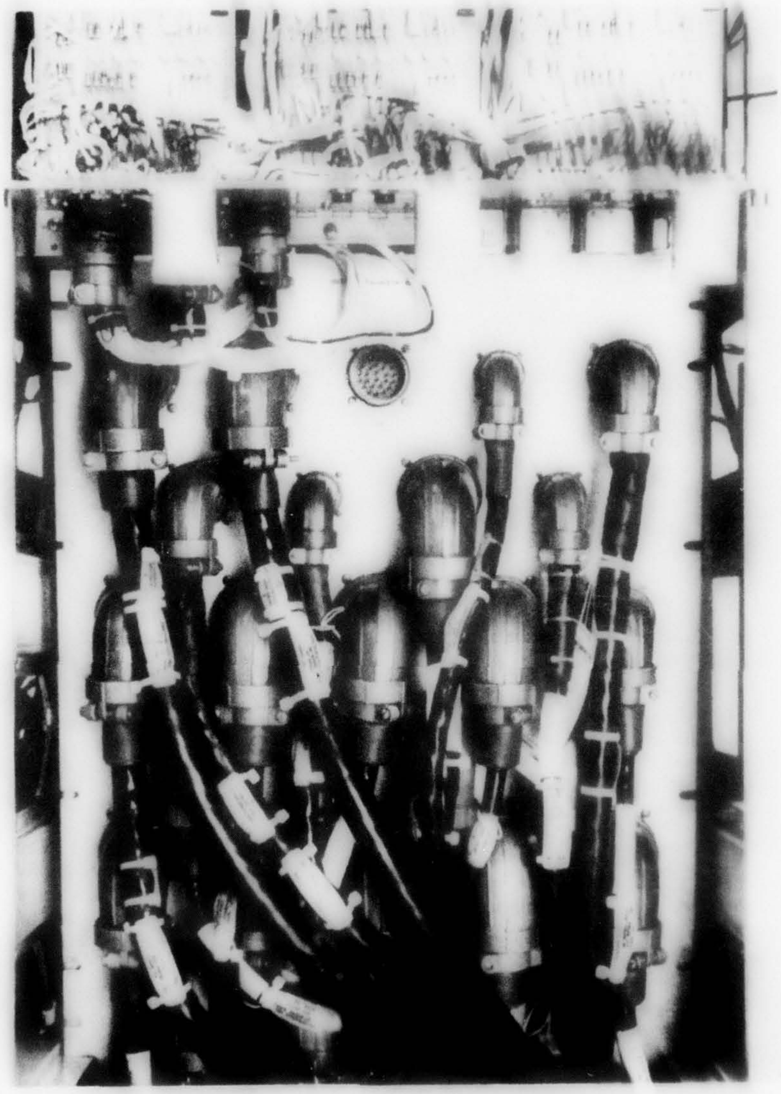


Figure 1. Conventional Cabling Pollution

	FIBER OPTICS	COAX
LOW COST	X	X
300° C TEMPERATURE	(GLASS)	X
VIBRATION	X	X
LOW CROSS TALK	X	X
NO CROSS TALK	X	
RFI, EMI, NOISE IMMUNE	X	
TOTAL ELECTRICAL ISOLATION	X	
NO SPARK (FIRE)	X	
NO SHORT DISABLING	X	
NO RINGING	X	
1000°C TEMPERATURE	(GLASS)	
EMP IMMUNE	X	
NO CONTACT UNRELIABILITY	X	
SIGNAL BANDWIDTH	$\rangle$ 1 GHZ	$\rangle$ 20 MHZ
POWER TRANSMISSION		X
PRODUCTION AND SUPPORT ENGINEERING		X
NEW TECHNOLOGY	X	
LOSS IN CONNECTIONS AND SPLICES	X	

Figure 2. Comparison of Cable Features

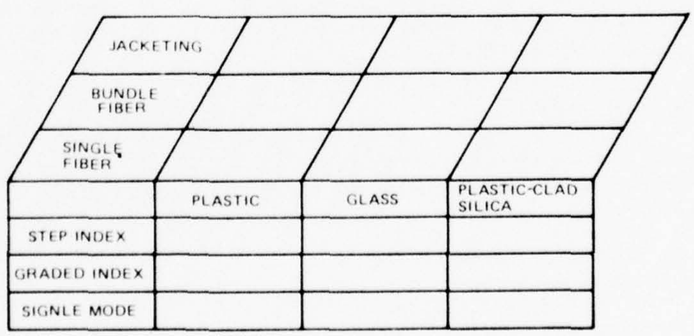


Figure 3. Fiber Optic Cable Selection Tradeoffs

and is surrounded by an outer tube of lower index, we have a step index fiber. When the index varies linearly from the center to the outer edge, we have a graded index fiber.

The following three classes of cable are presently being produced today:

	PLASTIC	GLASS	PLASTIC CLAD SILICA
Cost	Low	High	Medium
Loss	Mid-High	Low	Low
Handling	Excellent	Poor	Good
Environmental	Poor	Good	Good

3. SINGLE FIBER

One single strand of fiber optic cable enclosed in a protective jacketing. The jacketing is only for environmental protection since the fiber keeps the light energy wholly within its structure.

4. BUNDLE FIBER

A multiple strand fiber optic cable containing (7, 19, etc.) fibers each carrying the same light energy and enclosed within a protective jacketing.

5. FIBER LOSS

The amount of light energy loss in the fiber cable primarily caused by scattering and absorption. Cables are usually graded into three categories:

Low Loss ($<$10 dB/KM), Medium Loss (10 dB$<$L$<$100 dB/KM), and High Loss (100 dB$<$L$<$1000 dB/KM)

6. CONNECTOR/SPLICE LOSS

In contrast to coax systems, every connection/splice causes light energy loss primarily due to misalignment, reflection, and absorption. Present day connectors introduce three to six dB of loss depending on whether they are single fiber or bundle connectors. Also, connector availability is very suspect at the present time, but it is bound to improve. Laboratory splices have been made in the .1 to .2 dB range, but there is a great need for field repair methods and equipment.

7. RECEIVER

A receiver circuit accepts light in the 10 to 100 nanowatt range and produces TTL compatible outputs (0-5V).

8. TRANSMITTER

A transmitter circuit accepts TTL level inputs and produces one to ten milliwatts of light power out of an LED.

9. "T" CONNECTOR

This is a passive optical tap that allows energy to be extracted from a fiber optic cable and allows optical energy to be interjected into the fiber optic cable from a receiver/transmitter (R/T) port.

10. RADIAL ARM COUPLER

This is a passive optical device that allows the light energy from one fiber optic cable to be divided into an optical signal on many fiber optic cables. The following two types of radial arm couplers are presently in use today:

a. Reflective: A reflective radial arm coupler contains a mixing rod and a mirror. Every R/T port is connected to the coupler by only one fiber. Light energy coming from one R/T into the coupler is reflected back on the fiber cables to all other R/T ports.

b. Transmissive: A transmissive radial arm coupler contains an input port of fibers, a mixing rod, and an output port of fibers. The light signal from any R/T is thus sent to all R/T's by the coupler. This type of radial arm coupler is the simplest to mechanize and presently the lowest in cost.

FIBER OPTIC ADVANTAGES

The recent announcements of fiber optic cable TV systems in New York, London, and Tokyo along with the first operational telephone system in Chicago (Bell) and Long Beach (GTE) should convince doubters that fiber optic technology is here today.

Why should one be interested in fiber optics systems for trainers? The major reasons are bandwidth and noise immunity.

Figure 2 tabulates the comparative features of fiber optics, and coax. Each line on the chart endeavors to show a fair comparison. For low cost, the common factors are the same cable size, flexibility, equivalent bandwidth, and manufacturing quality.

Fiber optics or coax offer a fairly even choice in the first four categories. If one wants a low crosstalk or no crosstalk (that is, no measurable crosstalk between adjacent fibers in a fiber bundle), one would want to use fiber optics. Since there is no crosstalk between adjacent fibers, there is certainly no crosstalk between adjacent fiber cables.

Fiber optics, being made of a dielectric, provides ideal RFI/EMI noise immunity. They do not pickup, nor do they radiate any signal information. Fiber optics also provides total electrical isolation between the sending and receiving terminals, eliminating any common ground and the problems that are associated with common grounds (voltage offsets, ground currents, ground noise, pickup, etc.). There are no spark or fire hazards with fiber optics should the fiber optics be damaged. There is no local secondary damage incurred because no sparking, heat, or electrical energy dissipation of any sort takes place. There can be no short circuits or circuit-loading reflections back to the terminal equipment if a fiber optic cable should be damaged. In wire systems, the damage to a cable may cause reflected damage into the terminal circuits by shorting, grounding, or dangerous potentials and currents in the wires. The fibers do not conduct electrical current and, thus, eliminates this problem.

Fiber optics have EMP immunity for the same reason — they have RFI/EMI immunity. Wire systems suffer from connector discontinuity problems because of the need for good physical contact connector interfaces for signal transfer. Proper polishing of the optical interface between light source and the fiber optic bundle provides a signal connection requiring no physical contact. The light energy signal passes through the small air gap between the devices and the end of the fiber optic bundle. Grits and opaque materials, however, decrease transmission or damage connector surfaces if proper procedures are ignored. Temperatures up to 1,000^{o} C may be withstood by certain glass systems. Most present fibers are stable well beyond 300^{o} C.

Assuming an acceptable fiber loss factor in the range of 50 dB/km, one finds a 200 megahertz limit with fiber optics for a 300 meter length. Coax, according to handbook data, is limited to 20 megahertz for the same cable size and length, and a twisted wire pair to 1 megahertz. Fiber optic systems with bandwidths over 100 megahertz should be considered laboratory systems at present, and not quite ready for deployment. Potential signal bandwidth with single mode fibers is calculated to be above 1 gigahertz.

FIBER OPTIC CABLE

The selection of a fiber optic is very important. However, one is immediately faced with a number of decisions, claims, and counterclaims. In reality, the application will drive the selection of the cable used, and that in turn drives the selection of light energy sources, detectors, and electronics. Figure 3 is a three-dimensional representation of the trade offs required in selecting a fiber optic cable.

ELECTRONICS

A rapid evolution is taking place in the electronics associated with fiber optic systems. Up to today, the high cost of fiber optic cable and discrete component designs have been the driving factors in system sensitivity analysis. Presently, however, we are in the second step of the evolution where the electronics is being packaged in hybrid and monolithic form. Finally, we will see totally integrated sources, detectors, and all electronics in one DIP package. Figure 4 depicts this evolutionary process.

Fiber optic technology is thus moving from the "scab on" (mounted external to the existing equipment) to the equipment design philosophy. To be cost effective, fiber optics must be the first design approach and not a backup.

TRAINER SYSTEM APPLICATIONS

If we look at a modern trainer like Honeywell's Sonar Operator Trainer or Device 14E27, we see two areas of application for fiber optics.

First, we need intra-cabinet "point-to-point" data links (Figure 4). Because our systems contain totally modular, distributed, self-diagnosed, and stand-above cabinets; the ground isolation, noise immunity, bandwidth, and elimination of copper make fiber optics a cost effective solution today. Imagine a large digital system generating sonar waveforms which are to be converted to low-level analog signals. These signals will then be used to stimulate operational sonar hardware at the low-level hydrophone inputs. Also, the sonars contain spectrum analysis equipment which are very sensitive to coherent noise. Historically, ground noise in a system like this has been a constant source of trouble. Fiber optics communications has no common or ground return.

A number of ways have been discovered for taking advantage of the fiber optic characteristics for multiple channel communications. As we now know, there is no measurable crosstalk between adjacent fibers in a bundle, and

Figure 4. Time Line of Fiber Optics Development

thus, no crosstalk between groups of fibers. The fiber optic bundle may thus be subdivided with each group of fibers being a separate, parallel, channel. This concept may be extended to a single fiber per channel if one can afford to give up the redundancy in a group of fibers.

Light sources with different wavelength characteristics (colors) may be employed to add to the data capacity of fiber optics. This wavelength (or carrier frequency) "multiplexing" allows several channels to be carried on a fiber bundle, subgroup of fibers, or even on single fibers. Practical limits are presently about five colors in the range from visible red (~6500A) to the near infrared (~9300A). Various combinations of all three "multiplexing" techniques may be used to enhance greatly the data capacity of fiber optics.

Second, we need multiplexed data busses for microprocessor based distributed systems that are being developed today. Fiber optic data bus developments are the biggest R&D areas today. Figure 5 shows the "T" and "star" data bus configurations being developed today. The "T" system is the most like a coax system, but it has two major drawbacks: First, a passive system sustains so much loss per port that eight taps is about maximum; and second, if repeaters are placed at the taps to overcome signal loss, the system reliability is reduced significantly.

The "star" uses a radial arm coupler which is being developed by many companies today. This concept requires low-cost fiber and low signal loss connectors. Both requirements are becoming facts today. In the next few years, we will see this type of data bus predominate because it overcomes the problems associated with the "T" coupler.

FUTURE

The path is very clear and fiber optics is in wide usage. There is enough performance/cost/environmental data to perform systems and product studies.

As we view the situation:

1. Fiber costs will decrease steadily. Monolithic and integrated optical/electronic modules are in the product development stage and will provide low cost systems.

2. Fiber optics will reduce the cost of trainer systems by allowing wider band data transmission with total electrical noise immunity.

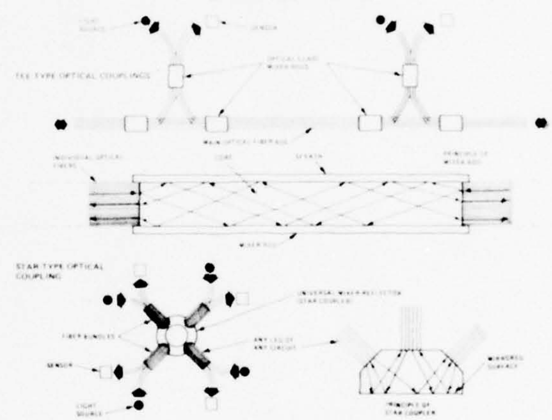


Figure 5. Fiber Optics Cable Configurations

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F-15 AIRCRAFT FLIGHT SIMULATOR STUDENT PERFORMANCE MONITORING AND SCORING

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SUMMARY

Simulators, or trainers, have been available for years. These devices have developed from ingenious mechanical gear, to electrical-analog controlled equipment, to the present sophisticated, digital computer-controlled designs of today. Simulators now exist that help train personnel to operate virtually any mechanism invented. These include ships, airplanes, trains, automobiles, orbiting vehicles, advanced radar, etc. Much effort has been expended in defining and refining trainer hardware and software to develop a simulator of greater and greater fidelity to the performance of real-life equipment. This is only fitting and has resulted in succeeding generations of simulators performing in increasingly compatible performance to their models. The F-15 simulator, itself, is a technical marvel in synthesizing the characteristics and capabilities of this high-performance jet aircraft.

However, perhaps because of American industry's strides in perfecting the performance of simulators, greater attention has now focused on training methods and student performance evaluation. On earlier trainers, the progress and final testing of students has been influenced by subjective ratings of the instructor.

Certain specific skills obviously must be learned by students to be able to "fly" an aircraft simulator from airfield "A" to point "B" and return. Otherwise the student may 1) crash, 2) lose his way, 3) perform otherwise noticeably erratically, and would be relieved of his student classification. While very objective tests or problems thus eliminated the ineffective pilots, the instructor-pilot (IP) was left with the now formidable and quite-subjective evaluation of the relative performance of the remaining "good" pilots. The IP's judgement now had to overcome the "fog factor" of his own preferences and prejudices of what constitutes good flying, his own alertness during all parts of each student's test flight, his personal attitude toward individual students, etc. Then, pitting these low-control factors against other instructor's different prejudices, beliefs and personalities limited consistent, relative rating of students' abilities and progress.

Thus, the recent stress on more impersonal, comprehensive, and uniform evaluation of students' progress and final performance is certainly warranted. The benefits from any objective or "third party" test of students' performance are not only that uniform and fair testing results, but that even the training provided by the instructors becomes tailored to the common denominator (perhaps even improving some areas of teaching). The IP's will consciously or otherwise teach their students so they can score well on the tests they know will follow.

The scoring methods evolved during the development of the F-15 simulator include methods to evaluate student's flight and tactical performance. Flight scoring covers the ability of the student to correctly fly approaches to or departures from selected airfields. Tactics scoring involves the evaluation of the student's techniques and success in releasing weapons at ground or airborne targets encountered randomly during a simulated mission.

Fig. 1 is a schematic diagram, showing the basic elements of the monitor-scoring sequence. Before flight, and for a large number of airfields, data for the plan and elevation view for a CRT display of approach or departure plates were entered on disc with "MOD SUPPORT" programs. This allows the IP to select one of a library of approaches or departures to be displayed on a large CRT for subsequent flight by the student and scoring at the end of the mission. Before flight, the approach or departure is segmented into separate legs. These are also entered on disc files associated with the CRT data for the airfield picture using "MOD SUPPORT."

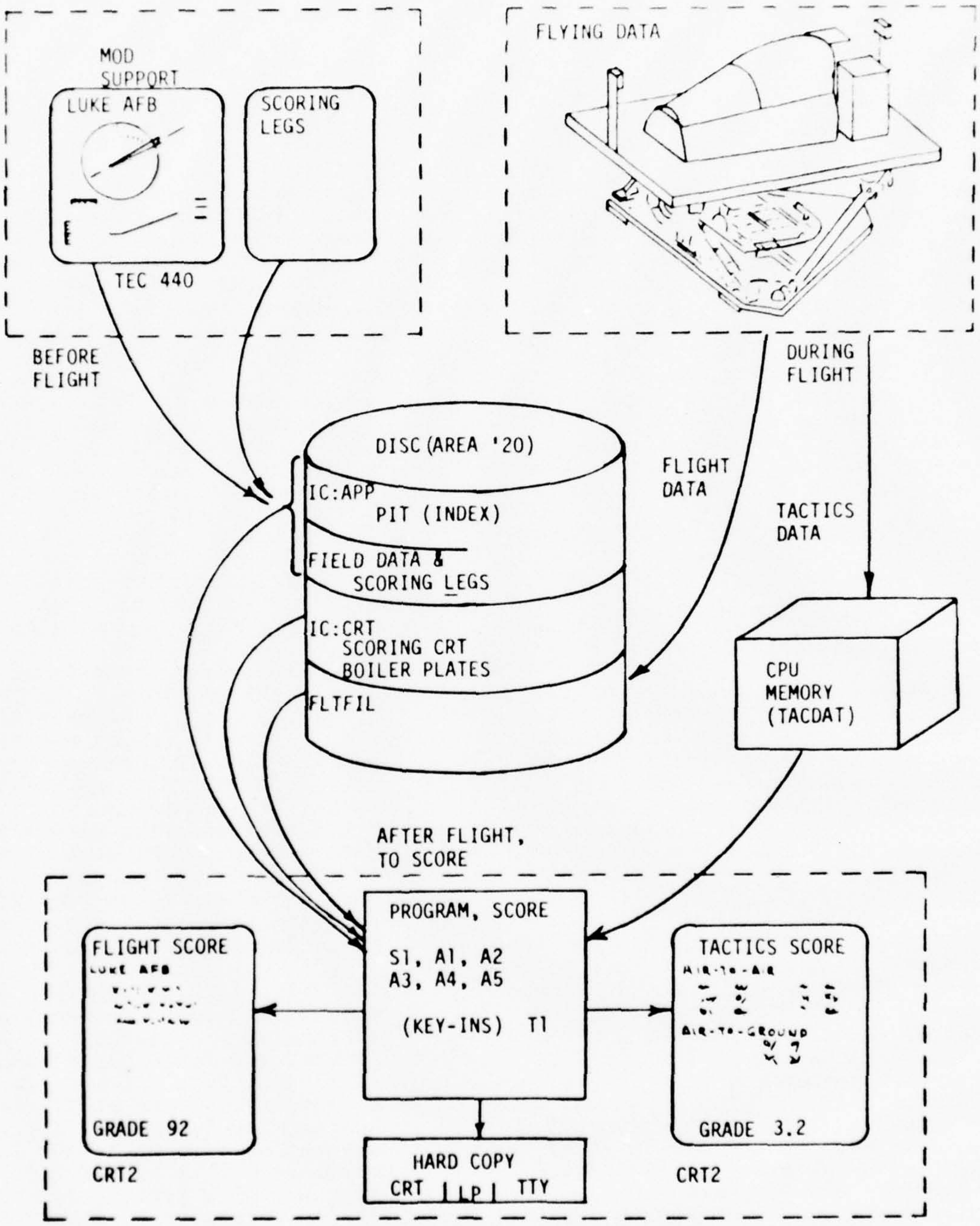

Figure 1. Schematic Diagram of Scoring

Additional scoring leg data placed on this disc file includes the variables to be monitored during each leg, the variables which define the end of each leg, the tolerances to which these values must be met, time delay on scoring any leg, etc. During the mission, the IP may call up any one of the stored airfield plates onto a display CRT. A number of flight parameters are saved once per second when the student flies within a 20 nm circle around the field. The instructor may watch the real-time progress of the F-15 by observing various flight parameters such as speed, altitude, heading, pitch, engine RPM, etc. on the center CRT while a "bug" representing the F-15 position, one on the airfield plate plan view and another on the side view, are flying to scale on the right hand CRT. After the mission is complete, the instructor may score the student's approach or departure for as many as five fields flown during the mission. The student is graded 100 with deductions proportional to time and magnitude of flight error compared to the prescribed approach or departure. The airfield name, approach or departure name and the student's score are displayed on the center display tube. Also shown are each error event and detail data of what parameter, when, how much, and how long it occurred. Separate scores are calculated for each scored approach or departure. If desired, the IP may make a hard copy of the CRT-displayed scoring pages. These can be KRATOS (copy of the CRT), TTY, or line printer (available at Luke AFB only). Finally, the IP may elect to have a hard copy of all the flight data saved in core for any or all the scored approaches or departures.

Tactical monitoring and subsequent scoring may be performed on the same or separate mission as flight scoring. Prior to the mission the IP may elect to have up to 15 emitter-targets (ET's) come into radar view automatically during the mission. He would use "MOD SUPPORT" to set up the type (ground, airborne, emitter, emitter-target), location (for ground target), range, bearing, altitude and path (for airborne targets). During flight, these the IP could let these ET's appear at predetermined times as planned, or could override and enter new targets as he saw fit. The student must then take positive action to report the ET via radio, achieve radar lock on, and finally select the appropriate weapon and release it at the target. This data is saved at time of weapon release along with other pertinent data depending on the mode of attack (air-to-air, air-to-ground), and displayed along with the "hit or miss" calculation based on ET path and weapon trajectories or on ET-firing envelope for certain weapons. Finally, an average score for the release (at scored ET's) of all weapons utilized during the mission is calculated based on four for an ET "kill" and zero for an ET "miss." During this tactical exercise, the student is allowed only one weapon release (this includes one release for a "stick" mode drop of several bombs or one release for a single trigger pull on cannon fire for as many individual rounds that are fired during that trigger pull).

After the mission the IP may score the tactics performance. The center CRT will then display the ET number, the hit or miss code (PK of 1 or 0) and other pertinent data depending on the attack mode for each ET. Hard copy of this display can also be made as for the flight scoring pages.

THE SIMULATOR

Goodyear Aerospace developed the F-15 simulator under Contract No. F 33657-73-C-0701 from the McDonnell Douglas Corporation, St. Louis, Missouri. Fig. 2 is a sketch of system hardware approximately in final configuration.

The major simulator components include:

1. Cockpit section, GAC, with full instrumentation, controls, and sounds. A coated canopy for instrument flying is currently supplied.

2. Motion platform, CAE Electronics, Ltd., Intermediate 6-Degrees of Freedom Motion System; vertical, lateral and longitudinal movement of 60", 60", and 40" respectively; pitch, roll, and yaw of 40°, 40°, and 30° respectively; load capability includes personnel cockpit, and consoles plus 8000 pounds (for a future visual system).

3. Computers (three), Harris Mfg. Co., Model 6024/4 minicomputers,

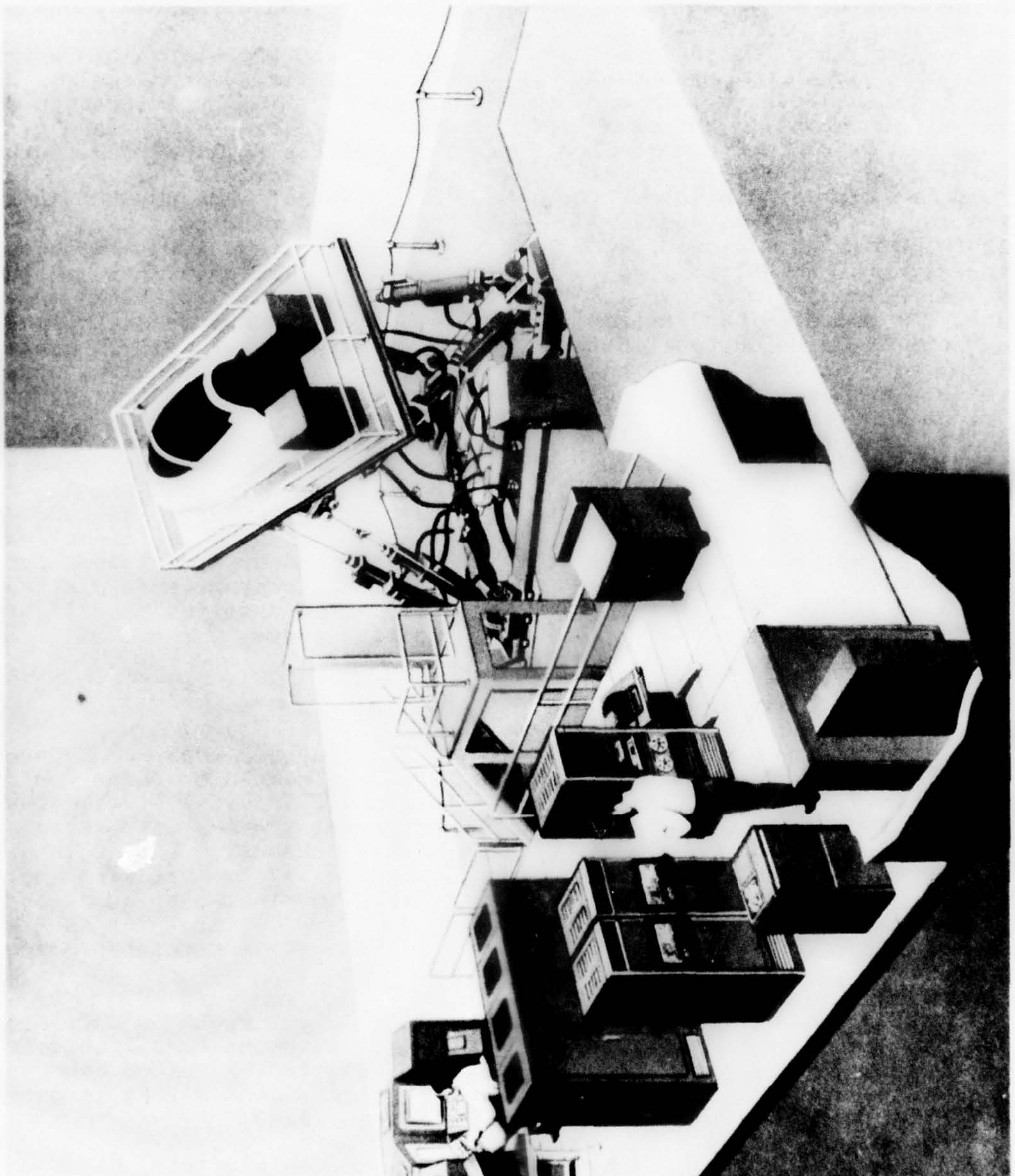

Figure 2. F-15 Flight Simulator

64000 (24-bit) words each, .75 usec per cycle.

4. Moving head disc, Information Storage System, Inc., Model 7140 Disk, 28 megabytes, 12 to 100 millisecond retrieval time.

5. Paper tape unit:

   a. Punch, Teletype Corp., (BRPE) Model 6003, punches 5, 6, 7, 8 level tapes at 110 characters per second.

   b. Reader, Digitronics Corp., Model 6002, reads 300 characters per second (photoelectric).

   c. Handler, Digitronics, Model 6040, paper tape handler.

6. Electrical equipment racks, GAC, power supplies, switches, breakers, A-0 and D-A converters, etc.

7. Instructor console, GAC, three CRT display tubes (Adage, Model 420 Graphics Display), system controls for display and F-15 cockpit interaction, annunciator and intercom, sound level controls, Kratos Model 7000 Graphics Hard Copier, Teletype R035 Teletype Printer, TEC Model 440, Alphanumberic Display Unit.

8. Digital Readout Unit, Goodyear Aerospace Corp., Model DRU, will display octal, scaled fixed point or floating point values of any register or address during execution. It operates in STOP, HALT, TRAP, or RUN mode to control the computer. It can display contents of a register or address each time a TRAP address is referenced. It is used for maintenance and test.

9. Maintenance and equipment room which will store necessary supplies and maintenance equipment and provide soundproof concealment for the following equipment.

   a. Hydraulic pump unit, Vickers Div. of Sperry Rand of Canada, Ltd., 3-50 HP and 1-5 HP motor for hydraulic pumps with controls, tanks, etc.

   b. Air compressor, Gast, for pressure to anti-g suit.

   c. Water pump and water cooler units.

While considerable project insight and direction during the development came from the contractor, McDonnell Douglas, much of the conceptual effort came from the United States Air Force. Air Force personnel from the F-15 System Program Office (SPO), the Aeronautical Systems Division (ASD), both from Wright-Patterson Air Force Base, Dayton, Ohio, and Tactical Air Command (TAC) from bases around the United States met with McDonnell and Goodyear technical and contractual personnel at three detailed meetings. These were the Preliminary Design Review (PDR), Critical Design Review (CDR), and the Critical Design Conference (CDC). At these meetings specification points were reviewed and clarified; design and hardware concepts from overall philosophy down to detail operational data were modified and approved; and final design and assembly proceeded.

After assembly of the first unit at GAC, both McDonnell and the Air Force, separately, conducted perhaps the most comprehensive acceptance tests imposed on an aircraft simulator to date. Every major subsystem, aerodynamics, propulsion, radar, central (on-board) computer, etc. was given detail performance evaluations to Acceptance Test Procedures (ATP's) that were prepared by specialists in that area from McDonnell engineering. These tests were reverified by the Air Force.

The completed simulator can navigate worldwide. It can carry the full (and variable) armament load of the F-15. It can release these weapons at a library of ground or airborne emitter-targets (ET's) that may emit electromagnetic radiation as desired. Radar and associated ANMI display are true-life functional to provide the target visibility for tactical operations. A fully-simulated Heads Up Display (HUD) is provided. Sound, motion (including details such as tarstrip impacts while on the runway) and motion cues are provided. On board computer, of the IBM, 4-PI family (8K, 32-bit words) is simulated for navigation calculations, HSI,and ADI control; to provide range and lead calculations for guns, bombs and missiles in attack mode.

The instructor can initiate malfunctions from a 125-set library and observe student corrective action. The three CRT's allow real-time observation of (on the left) cockpit radar and ANMI displays and navigation aids, IFF, AAI, and communications panels, (on the center) the HUD (pitch, roll, heading, speed, and altitude) and a number of other flight and engine variables, and (on the right) the initial position pages, approach plates, 3D-display, malfunctions, radio station pages, tactical (ET intrusion) sets, stores/weapons configurations, environment, etc. Most "library" data can be changed to suit new or different areas and circumstances with "MODIFICATION SUPPORT"-prompted cues on the TEC 440 for teletype response by an operator.

To capsulize--the F-15 may navigate worldwide, fly into almost all flight or tactical real-world situations with a variable load of stores and weapons. Many true emergencies may be simulated and finally a comprehensive flight and tactics scoring capability is provided.

FLIGHT MONITORING

To monitor or save data for scoring, the IP must first select the desired approach or departure field from the library. This "plate" is displayed on the right hand CRT. If the student is within the 20 nm circle around the airfield, a set of twenty-two variables is saved each second. These variables are shown in Table 1.

TABLE 1. FLIGHT DATA BUFFER

1. speed	9. localizer deviation	17. gross weight
2. altitude	10. tacan radial	18. airborne flag
3. heading	11. tacan distance	19. problem time
4. climb rate	12. tacan channel	20. nm to ¢ of circle
5. turn rate	13. F-15 configuration	21. F-15 in OM beacon
6. angle of attack	14. F-15 in MM beacon	22. end of flight
7. roll angle	15. latitude	
8. glide slope dev.	16. longitude	

The data saved each second is packed "on-line" into two 5-second buffers. As each buffer is filled, it is transferred to disc storage (disc file, FLTFIL, in Fig. 1, p.2). Each area reserved for a single, scored flight is 240 sectors long and can store data for about 80 nm at an average speed of about 250 knots, or a total of 20 minutes (1200 seconds) of flight.

Up to five approaches or departures (in any mix) for which approach or departure plates exist can be monitored and scored. Provision is made for 90 such plates. They can be changed to different airfields or simply modified by an interactive display on the TEC 440 display unit (controlled by "MOD SUPPORT" programs) and the manually-operated R035 teletype.

For a departure, the IP must select the departure plate for that airfield before the student becomes airborne on his takeoff. Otherwise, the subsequent, off-line scoring program would "lose" the F-15 and a poor score would result. Departure data is saved until the F-15 exits the 20 nm circle or 1200 seconds of data has been logged.

However, if the IP selects a different approach or departure plate while the student is still within the 20 nm circle, monitoring of that flight will terminate immediately. This departure (or approach) will count as one of the five scored flights. Later scoring will be performed on this flight up to the point of termination.

While flying a scored flight pattern, the IP may elect to observe the flight path of the F-15 marker on the right hand CRT display of the approach or departure plate. If he wishes he may replace this scene with other pages (except not another app/dep plate) and continue saving data. He may, for instance, select a malfunction page. He could then insert one or more malfunctions into the F-15 while still monitoring performance to the original approach plate. Reselection of the same plate would then allow the IP to continue observing the F-15 progress on the plate.

Termination of a scored flight also occurs if the student crashes. Scoring continues up to that point.

If the IP selects an approach page to an airfield from which the F-15 is outside the 20 nm ring, the flight data will be monitored from the time the aircraft enters the ring until:

1. Touchdown in normal landing.
2. Wheels are retracted after having once been extended.
3. The aircraft passes the normal ILS touchdown point.

A new approach may be monitored on another selected airfield, or on the same airfield (if this airfield is still the selected plate) if:

1. The landing gear is relowered within the 20 nm circle and the ILS localizer beam is reentered at or near normal intercept and altitude location.
2. The F-15 exits and reenters the 20 nm circle, regardless of configuration.

Upon penetrating the 20 nm circle on an approach, the student must proceed directly with the approach instructions. He may not enter a holding pattern partly or wholly within the 20 nm radial or the off-line scoring programs would be unable to track the F-15 to touchdown and an undeserved poor score would result.

TACTICS MONITORING

If the IP initiates tactics scoring and activates an emitter-target (ET) or a preselected group of ET's, a set of data will be stored in memory when the student aims and releases a weapon at the ET. The actual data displayed varies with the attack mode (air-to-air, air-to-ground [ex. CDIP], air-to-ground [CDIP]). This data related to mode is shown in the scoring section below. Table 2 shows the total set of data locations available for storage after weapon release. Data for a total of 15 releases can be saved during a single problem or mission. The trainer can monitor flight and tactics during the same problem.

While the student may aim and fire only one weapon at any ET, one release may include more than one projectile. For instance, a single release may include:

1. A single missile.
2. A simultaneous drop of several bombs.
3. A "stick" drop of "n" bombs.
4. A burst of cannon fire.
5. A crash while the ET is active.
6. The IP killing the F-15.

The latter two cases are, of course, not true releases, but are each counted as one of the 15 allowed releases. The only data available for these releases is the ET number, the variable, MISSION SUCCESS, (MI 2 for crash and MI 3 for instructor termination), and probability of kill of "0." The balance of the data is starred (***) on the scoring display. All data saved for the releases is stored in core for use at problem end for the off-line scoring program.

In the case of a drop of multiple bombs on manual or automatic aim, monitoring terminates for that ET as soon as one of the weapons scores a kill. The balance of the weapons are released but scoring will be based only on the "killing" bomb. Even on a miss, only one score will be counted for this multiple drop, and it will be based on the closest impact to the target.

To assist in positive training, the ET will disappear from HUD and radar screen immediately if a "kill" is made (PK=1). The ET is left on the CRT display after a "miss." No other active, scored ET's are allowed in view during scoring an ET. Only one scored ET may be on the screen at any time.

Actual "kill" or "miss" calculations vary with the type of weapon released. IR weapons require determination of "in-range" and sufficient received IR power for kill. Long and short range missiles require references to "launch envelope" to assess a kill. While for gun rounds and bombs, actual

TABLE 2. TACTICS DATA BUFFER

1.	score mode	9.	angle off to ET	17.	true airspeed
2.	ET number	10.	G-force	18.	roll angle
3.	radar acquis. time	11.	ET altitude	19.	miss distance to ET
4.	UHF call-in time	12.	ET heading	20.	impact bearing to ET
5.	weapon launch time	13.	ET ground speed	21.	ambient air temp
6.	mach number	14.	probability of kill	22.	ambient air temp
7.	altitude	15.	mission success	23.	ET vertical speed
8.	slant range to ET	16.	pitch angle	24.	aim point error

ballistic trajectory is calculated to determine intercept with a moving (or stationary) ET.

Some of the parameters shown in Table 2 require additional description:

1. Miss distance (See Fig. 3). This is the distance of impact of a bomb from a ground target.

2. Impact bearing (See Fig. 3). This is the angle from F-15 heading of the line from impact to target.

3. Angle off (See Fig. 4). This is the absolute angle between the line extending aft through the longitudinal axis of the ET and the line drawn from the F-15 to the ET. It may vary from 0 to 180°.

4. Aim point error (See Fig. 5). This is the effective ground separation of aim point to target as measured by the distance between the HUD reticle and the target designator on the HUD display.

5. "Stick" or "ripple" mode release (See Fig. 6). This sketch shows a 5-weapon stick and the Δ or impact bearing that would show on a subsequent scoring display.

SCORING

Flight - Before flying an approach or departure for later scoring, data for the CRT display and the scoring legs must first be keyed into disc memory (See Fig. 1). There is space for ninety plates. Data for a large number of CRT displays (77) for various approaches or departures were keyed in during first-unit checkout. These are entered via the MOD SUPPORT mode. The TEC 440 CRT prompts the IP (or other technical personnel) for the necessary inputs which he then keys in on the R035 teletype. The scoring legs for a plate are similarly keyed in, aided by automatic prompts on the TEC 440. Fig. 7 is a FLIP CHART (High Altitude Instrument Approach Procedures) page showing the HI-TACAN RWY 33 approach to Holloman Air Force Base airfield. The circled numbers along the flight path were added by the author to show the seven flight sections or "legs" into which this approach is separated for the scoring leg table. A brief, descriptive outline of the table that was keyed in for the scoring legs on this approach is shown in Table 3. The table shows seven legs for this approach. For instance, the fifth leg shows three variables monitored, RADIAL @ 52° ±3°, SPDLEG which signifies that the F-15 must fly the handbook curve of Approach Speed vs Gross Weight within ± 5 knots, and AOA (Angle of Attack) of 21 ± 1 unit. The transition point or end of this leg is reached at 2.8 ± .2 or 3 DME.

Table 4 shows fifteen variables that may be selected to either be monitored (3 max. to any single leg) or to be set for the leg transition point. The IP will use these three-letter variable names when building or modifying approach or departure scoring legs for the "approach plates." The interactive prompting, for instance would request, "MONITOR." The IP would then key "RAD" and a nominal value "152" tolerance of "±3" for leg 1, etc.

Flight scoring maximums:

No. of legs	16
No. monitored variables/leg	3
No. variables to end a leg	2
No. of tolerance types	2

The tolerance types include the usual ± to a nominal value and + ( ), $-\bar{0}$ as at leg 4 of Fig. 7 when altitude of the aircraft must be 5500' + 50, - 0.

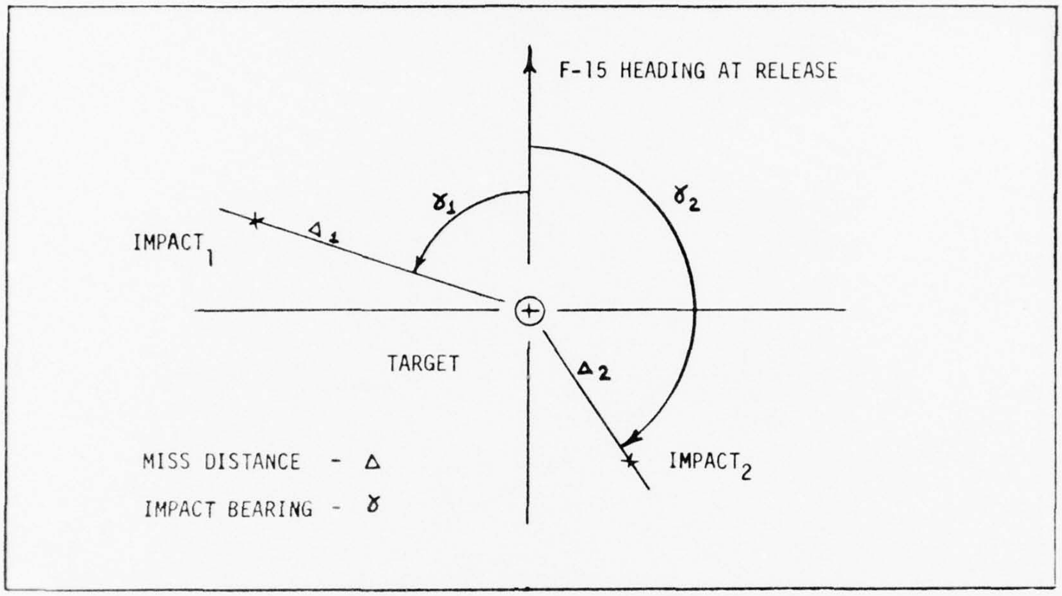

Figure 3. Miss Distance and Impact Bearing

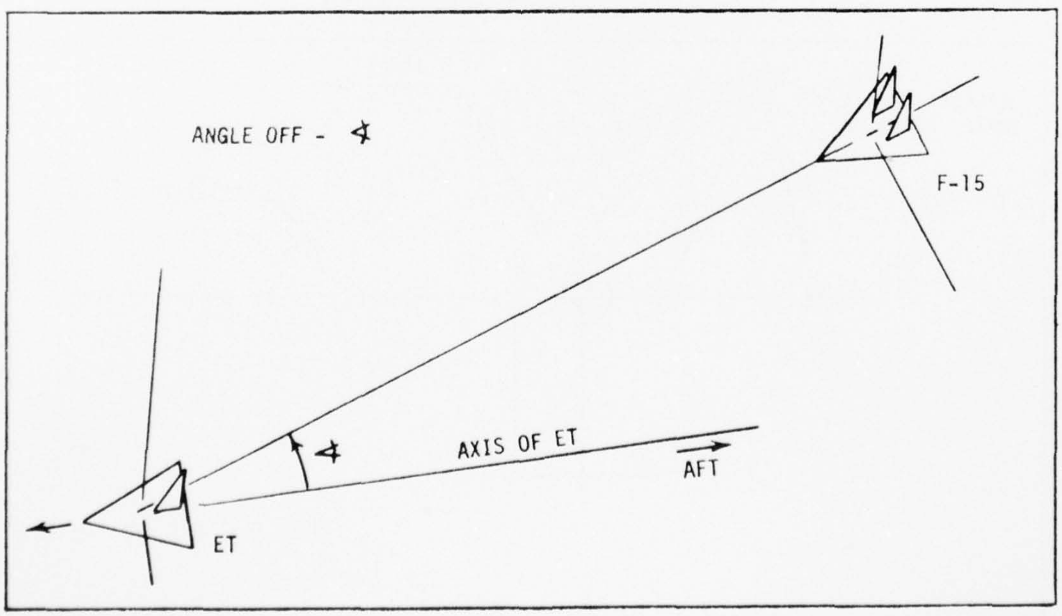

Figure 4. Angle Off

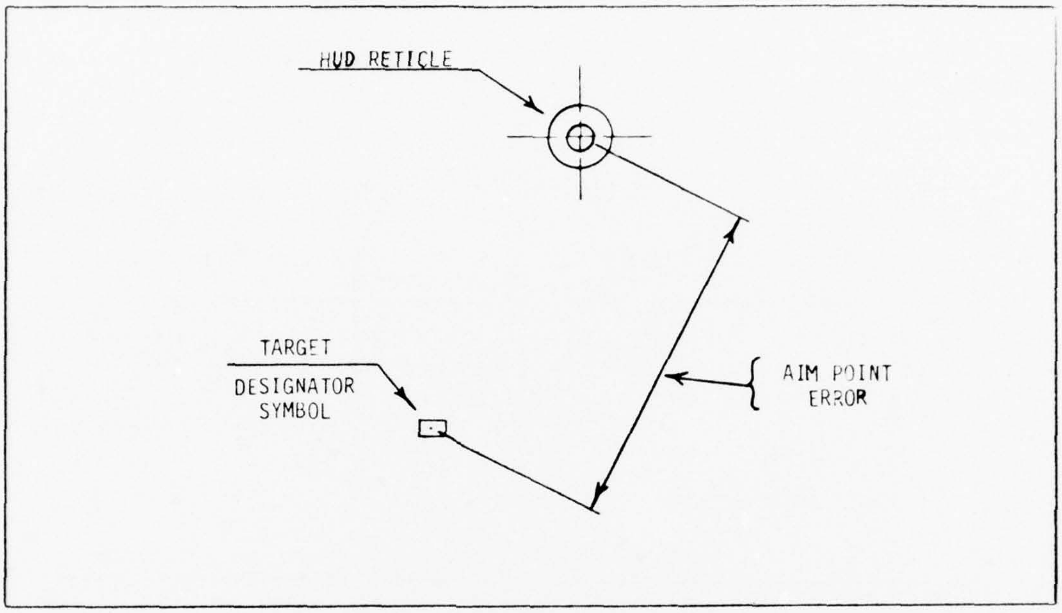

Figure 5. Aim Point Error

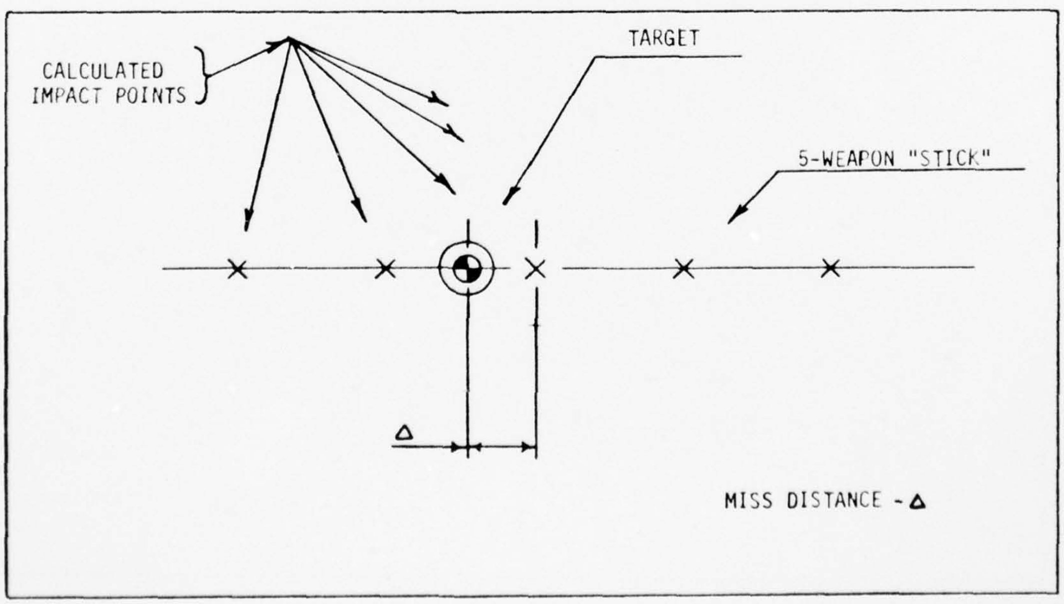

Figure 6. "Stick" or "Ripple" Mode Weapon Release

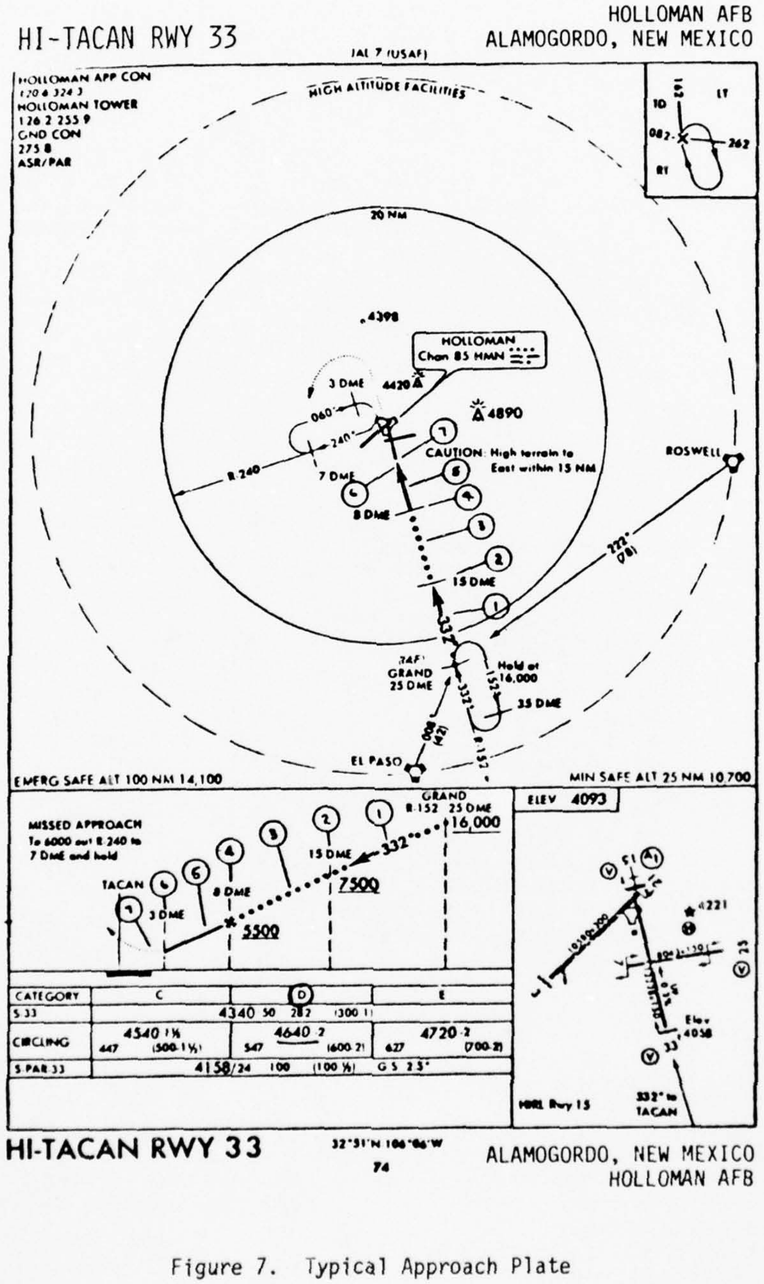

Figure 7. Typical Approach Plate

TABLE 3. SCORING TABLE FOR HI-TAC, RWY 33, HOLLOMAN AFB

Leg	Maneuver	Transition	Monitor	Remarkd
1	Straight descent	DME=14.8±.2	RAD = 152±3 HDG = 332±5 ALT = 7500±5000	Penetrate 20 nm ring @ 11,800' altitude
2	Check point	DME=14.8±.2	ALT = 7500+200	Alt. check @ 15 DME
3	Straight descent	DME=7.8±.2	RAD = 152 ±3 HDG = 332±5 ALT = 5500±2200	
4	Check point	DME=7.8±.2	ALT = 5500+50 CFG = 6+1	Alt. check @ FAP. Wheels, Flaps, SP brakes dn/out.
5	Final apporach	DME=2.8±.2	RAD = 152 ±3 SPDLEG AOA = 21±1	Speed to be a function of gross weight
6	Check point	DME=2.8±.2	ALT = 4340±50	Altitude check @ 3 DME
7	VFR	Last Leg	SPDLEG AOA = 20+3 CFG = 6+1	Fly to touchdown

TABLE 4. SCORING LABELS FOR APPROACH PLATE SET UP

Scoring Labels	Descriptive Name	TEC Input Units	Scale
SPD	Calibrated airspeed	knots	B12
ALT	Altitude above sea level	feet	B6
HDG	Heading (0 to 360°)	degrees	B5
CLM	Rate of climb	ft/min	B0
TRN	Rate of turn	deg/min	B5
AOA	Angle of attack	AOA units	B17
ROL	Roll angle	degrees	B5
GSD	Glide slope deviation	degrees	B5
LOD	Localizer deviation	degrees	B5
RAD	TACAN radial (0 to 360°)	degrees	B5
DME	TACAN range	nm	B10
CHL	TACAN channel	--	B0
CFG	Configuration	--	B0
MMB	Middle Marker Beacon	--	B0
OMB	Outer Marker Beacon	--	B0

SCORING ALGORITHM - FLIGHT

The flight scoring algorithm is Eq. 1, shown below. The algorithm allows a student a score of 100 for a normal departure or approach. Each flight is scored individually. The acutal flight of the F-15 is compared to the required vertical and positional data shown on SIDS (Standard Instrument Departures) and FLIP charts. Tolerances to these plate variables and other monitored variables (such as speed) consistent with good flight practice are allowed. If the student exceeds the tolerance on the monitored variables, he is penalized percentage points depending on the time and magnitude of his intolerance. His final score is 100 less the accrued deductions.

Item	Deduction
Out of tol. on any monitored parameter (ea. time)	1 x N
50% over tol. (ea. time)	2 X N
100% over tol. (ea. time)	3 X N
Wrong tacan channel	1 X N

N = No. of 1/2 minutes in each out-of-tol.

Score = 100 - $\sum$(deductions above) Eq.1.

Obviously, other factors than those monitored by the scoring program will be watched by an alert IP. These can include the handling of malfunctions or unusual flight conditions, the verbal check-off procedures that the student follows with ground control, his actual flying "touch" or technique and a number of other items. But his numeric grade providing an unbiased comparison of performance on identical missions to his classmates' scores will be a telling measure of performance.

SCORING ALGORITHM - TACTICS

The tactics scoring algorithm is Eq. 2.

$$\text{Score} = \frac{\sum_{1}^{n} (4 \ * P_{K})_{n}}{n} \quad \text{Eq. 2.}$$

n = number of different weapons released (or bursts of gun)

P_K = probability of ET kill (= 0 or 1)

For each successful weapon launch P_K, (probability of kill, is one), the student is given a relative grade of four (4). For each unsuccessful launch (missed target and P_K=0), a grade of zero (0) is given. These individual grades are then averaged for a net, single grade for the mission. This final score will, of course, range from zero to four.

There are other variables automatically logged at time of weapon release. These are printed out after the mission upon request. These are shown below in the section on Scoring Displays. These variables include (depending on the attack mode) radar acquisition time (after ET was activated on radar), time to launch an offensive weapon, etc. These variables are printed out for the IP's use in a more subjective analysis. While these additional data items are not automatically (by the computer) assessed, they are supplied and contribute to an overall evaluation of the student's tactical performance as determined by the IP.

SCORING DISPLAYS

Fig. 8 shows the display that appears on the right hand CRT when the IP ends the problem or mission. This page displays all the cues to prompt the IP for the scoring or data displays he wishes to see, or to exit without scoring. For instance, he would key "S1" for the Flight Scoring Display; "T1" for Tactics Scoring Display; "A2" for the data saved during the second scored flight, etc. If he did not wish to score the last problem, he could key in "C" to allow him to initiate and fly the next problem. Cues are also provided him to allow hard copy of any of the scoring displays. Finally, there is a set of messages to remind the IP if he keys a wrong code. These latter messages appear in the space called "ERROR MESSAGE" on the MENU page.

A sample of a Flight Scoring Display is shown in Fig. 9. This shows seven errors the pilot committed in departing Luke AFB via FLATIRON-TWO departure. He had four out-of-tolerance conditions on the first leg, two on the second, and one on the third leg. On leg 3, for instance, at problem time, one minute and three seconds (1:03), at 18.8 nm DME, and on the 151 degree radial, his aircraft heading was out of tolerance. Its maximum (or minimum) limit was 33.4 degrees, and he was off heading nominal (plus tolerance) for 32 seconds.

Fig. 10 shows a sample of Flight Data Printout. This is a copy of the flight data saved in core and transferred to disc storage during a scored flight. If the IP wants to review actual flight data for one of the scored flights, he will key in the correct code and get this data printout.

The Tactics Scoring Display is shown in Fig. 11. Three modes of attack are available to the student, Air-to-Air, Air-to-Ground (ex. CDIP), and Air-to-Ground (CDIP). (CDIP stands for Continuous Displayed Impact Point). Various data is saved for a weapon release depending on the mode as noted on the display. The student's total grade is not only the "SCORE" of 2.8 which represents his total success in hitting the several targets (4.0 is the score for "kill" of all targets), but also the IP's evaluation of the associated data on this page.

NEW SCORING CONCEPTS

The automatic scoring developed for the F-15 trainer introduces unique methods to provide impartial and detailed grading of a student's performance. These adequately

PERFORMANCE MONITOR

DATA AVAILABLE:

I. PERFORMANCE SCORING

S1 - FLIGHT
T1 - TACTICS

II. FLIGHT DATA

A1 - (Approach/Departure Airfield Name)
A2 - ( )
A3 - ( )
A4 - ( )
A5 - ( )

TO EXIT:
AN - EXIT TO MODE CONTROLLER

C - EXIT TO FLIGHT FOR NEXT PROBLEM

KEY IN CODE NUMBER ABOVE.
RESELECT NEW CODE IF DESIRED.
KEYIN NEXT CODE AFTER PRINTOUT,
IF ANY, IS COMPLETE.

HARD COPY OF DISPLAY:
CRT - PRESS 'COPY' BUTTON BELOW CRT 2
RO35 - PLACE FLIGHT CPTR. REGISTER SWITCH '0' UP
PRINTER - PLACE FLIGHT CPTR. REGISTER SWITCH '1' UP
NOTE: REQUEST COPY BEFORE KEYIN SELECTION ABOVE

(ERROR MESSAGE)

Figure 8. Performance Monitor - Data Menu

FLIGHT SCORING
DEPARTURE

AIRFIELD LUKE AFB FLATIRON-TWO

LEG NO.	P TIME	DME	RADIAL	PARAMETER	MAX.VAL	TIME OUT
1	0:00:43	16.4	125	SPD	309.0	1
1	0:00:42	16.2	125	RAD	124.3	3
1	0:00:44	16.5	124	ALT	12600.0	4
1	0:00:46	16.6	128	SPD	332.0	5
2	0:00:54	17.6	132	CLM	114	3
2	0:00:56	17.9	140	AOA	16.7	3
3	0:01:03	18.8	151	HDG	33.4	32

SCORE 87

Figure 9. Flight Scoring Display

FLIGHT DATA - LUKE AFB FLATIRON-TWO

TIME	0:00:41	0:00:42	0:00:43	0:00:44	0:00:45	0:00:46
SPEED(CAS)	314	312	309	0	0	0
ALTITUDE	12350	12400	12450	0	0	0
HEADING	37	317	0	0	0	0
R O CLIMB	442	-442	0	0	586	132721
R O TURN	120	-120	0	0	0	0
ALFA	3.3	3.3	3.3	3.3	3.3	3.3
ROLL	2	-7	0	0	0	0
GS DEV	0.25	-0.24	0.00	0.00	0.00	0.00
LOC DEV	0.60	0.00	0.00	0.00	0.00	0.00
T. RADIAL	129	0	0	0	0	0
T. RANGE	16.0	0.0	0.0	0.0	0.0	0.0
T. CHANNEL	27	42	43	44	45	46
CONFIG	0	0	0	0	0	0
LATITUDE N	30:29:00N	28:09:07N	0:00:00N	0:00:00N	0:00:00N	0:00:00
LONGITUDE W	-86:68:00W	-81:86:98W	0:00:00W	0:00:00W	0:00:00W	0:00:0C
GR WEIGHT	41387	41387	41387	41387	41387	41222
TOUCHDOWN	0	0	0	0	0	0
CTR RANGE	14.3	12.6	0.0	0.0	0.0	0.0

TIME	0:00:47	0:00:48	0:00:49	0:00:50	0:00:51	0:00:52
SPEED(CAS)	331	332	332	0	0	0
ALTITUDE	12520	12400	12300	0	0	0
HEADING	0	0	0	0	0	0
R O CLIMB	442	442	0	0	586	132721
R O TURN	0	0	0	0	0	0
ALFA	3.3	3.3	3.3	3.3	6.0	9.0
ROLL	0	0	0	0	0	0
GS DEV	0.00	0.00	0.00	0.00	0.00	0.00
LOC DEV	0.00	0.00	0.00	0.00	0.00	0.00
T. RADIAL	128	0	0	0	0	0
T. RANGE	16.7	0.0	0.0	0.0	0.0	0.0
T. CHANNEL	27	48	49	50	51	52
CONFIG	0	0	0	0	0	0
LATITUDE N	0:00:00N	0:00:00N	0:00:00N	0:00:00N	0:00:00N	0:00:00
LONGITUDE W	0:00:00W	0:00:00W	0:00:00W	0:00:00W	0:00:00W	0:00:00
GR WEIGHT	41222	412222	41222	41222	40000	40000
TOUCHDOWN	0	0	0	0	0	0
CTR RANGE	0.0	0.0	0.0	0.0	0.0	0.0

TIME	0:00:53	0:00:54	0:00:55	0:00:56	0:00:57	0:00:58
SPEED(CAS)	320	320	320	0	0	0
ALTITUDE	12300	12300	12300	0	0	0
HEADING	0	0	0	0	0	0
R O CLIMB	126	114	0	0	586	132721
R O TURN	0	0	0	0	0	0
ALFA	12.0	16.1	16.2	16.6	16.7	16.7
ROLL	0	0	0	0	0	0
GS DEV	0.00	0.00	0.00	0.00	0.00	0.00
LOC DEV	0.00	0.00	0.00	0.00	0.00	0.00
T. RADIAL	130	0	0	0	0	0
T. RANGE	17.5	0.0	0.0	0.0	0.0	0.0
T. CHANNEL	27	54	55	56	57	58

Figure 10. Flight Data Printout

TACTICS SCORING

AIR TO AIR

ET NO	27	12	4
ACQ TIME	3	***	9
CAL TIME	12	***	10
LNH TIME	21	***	11
MACH NO	0.63	***	1.60
ALTITUDE	41318	***	80000
SL RNG	5372	***	2000
ANG OFF	-5	***	-4
G-FORCE	1.06	***	2.00
APS-1G			
-3G			
-5G			
TGT-ALT	37285	***	81000
-HDG	87	***	180
-MACH	2.66	***	3.26
PK	1	0	1
MIS SUC	MA	MI 3	MA

AIR TO GROUND (EX. CDIP)

ET NO	42	15	21
ALTITUDE	40000	1000	8000
DIVE ANG	0	1	0
G-FORCE	1.00	1.20	1.00
T AIRSPD	474	131	355
BANK ANG	0	0	0
MIS DIST	50	30	5
IMP BNG	-54	-36	126
PK	1	1	1

AIR TO GROUND (CDIP)

ET NO	25	54
MIS DIST	10	1427
IMP BNG	69	-126
AIM ERR	8	1253
PK	1	0

SCORE- 2.8

Figure 11. Tactics Scoring Display

satisfy the needs and requirements expressed at the program definition for F-15. The techniques and capabilities, however, for additional or more in-depth evaluation have not all been examined on this project.

There are many other scoring concepts that could be applied for a more comprehensive test of student's skill. This paper is not appropriate for a detailed discussion of additional scoring potential but a brief outline of practical extensions will be noted:

1. Tactics Scoring: See Fig. 11. The score at the bottom of the page is simply an average of the 4's and 0's for "hits" or "misses" of the student's released weapons. The IP must, himself, provide weighted analysis of the other data on this page. The computer could handle the analysis of the rest of the data -- Are the radar acquisition times, the UHF call times, the weapon launch times too long? Is the slant range right for release of this weapon? Is this the right weapon? Etc.

2. Programs can readily be prepared to demonstrate certain aerobatic maneuvers. Similarly, additional coding can evaluate the student's skill in performing the same maneuvers.

3. Scoring can be utilized to determine the timely and correct response to a library of malfunctions.

4. Flight proficiency, that is, specific manual response to audio or visual cues, during turbulence, landing or takeoff can be determined.

5. The student pilot's ability to take adequate measures to prevent airborne collision with another aircraft can be measured. His response to imminent collision can also be determined.

6. Timely and correct procedures for electromagnetic countermeasures can be graded.

7. Navigation performance can be evaluated for various cross-country missions.

ABOUT THE AUTHOR

MR. JAMES T. DORSEY is a Group Leader in the Trainers and Simulators Department of Goodyear Aerospace Corporation. He has been with Goodyear Aerospace since 1952 and has participated in the design and testing of airborne and ground radomes, antennas, and microwave absorbers for the Defense Department. In 1967, he joined the Simulator Department. Since then, he has helped develop simplified control equations for submarine simulators, developed software for aircraft demonstration maneuvers, initiated software concepts for student evaluation and monitoring, and contributed to other software subjects related to simulators and trainers. Mr. Dorsey earned a B.S.E.E. at Northwestern University and the M.S.E. from Akron University. He is a registered professional engineer in the State of Ohio.

COMMERCIAL PARTS - NOW, LATER, OR NEVER

FRANKLIN W. ROZELL
Naval Training Equipment Center

Events of the past few years have forced government contractors to exert greater efforts on reducing their cost of operations. Cost for materials has naturally been one of the principle areas of concentration. Many contractors have concluded that these costs are needlessly high because of the government's insistence on using military type parts. A strong movement is, therefore, afoot to promote greater use of commercial parts. Papers have been circulated extolling their advantages; speeches are being made by political, business, and military leaders suggesting serious consideration be given to using available off-the-shelf type equipment and contractors are dismayed that requirements to use military type parts still exist.

On the contrary, we have seen or heard very little on the virtues of using military type parts. Maybe too many people have just taken it for granted that nothing need be said since this is just the way it has been for as long as most of us can remember. Manufacturers have innumerable facts about their products and can be expected to cite their advantages; however, only one government organization is actively gathering information on or promoting the use of military parts. Procurement Officers leave it to the specification writers and the specification writers are reluctant to change for a number of reasons that will be explained later. Also, no one group or organization within the government or private industry can possibly know the full cycle of operations, costs, maintenance tasks or support operations involved in all the types of standard parts. As an example, a standard relay is used in a diversity of applications, branches of service, and environmental conditions in the U.S. and foreign countries. We, at NAVTRAEQUIPCEN, may know how this relay is used in training devices, but not on other applications by other activities. It would help to have an unbiased thorough evaluation of each part as to why it is used, how it is used, who uses it, and what standards must be met for each application. However, the whole purpose of using military type parts is to avoid such costly studies and allow parts to be selected with full confidence that they will meet stated characteristics.

A requirement for a new approach is apparent. Conditions are changing and the government is lessening its resolve to stick wholly to military type parts. The wedge is economics and the necessity to obtain as much as possible for each obligated dollar. It is extremely difficult for procurement officials to explain why a contract did not go to the low bidder, and contracts with design-to-unit-production-cost clauses rely heavily on low acquisition costs. More and more commercial parts are creeping into government inventories.

This paper will present no startling new theories, no facts previously unknown to man, and no recently discovered data sources. However, we will try to present some basic reasons why the government does specify military type products, what efforts are underway that may offer some reasonable solutions and what changes we may expect in the future.

Cost Considerations

Since the heart of the problem is connected to economics, let us first examine the cost situation. One of the problems is that the pro-commercial users tend to concentrate on the initial or acquisition cost of these products and may not be fully aware of possible later consequences. The government is actually moving more and more to an analysis of the ultimate or life cycle cost as the prime consideration. Unfortunately, data on other than acquisition costs usually does not exist in a readily available data bank or cannot be acquired in the desired format.

Maintenance costs are a very serious problem for the DoD. Maintenance and operational costs account for over 70% of the 1978 budget. Such costs can easily be ten times the acquisition costs for the life of a training device. The DoD is already desperately seeking an inexpensive solution to this expensive problem.

Commercial parts place a heavier and possibly unnecessary burden on maintenance costs because they require special treatment in so many instances. First of all, they require that another

item be carried in inventory; they frequently require special tooling or test equipment over and above what is presently available; they require separate handbooks, manuals, and parts catalogs; they require individualized training of personnel for operation and maintenance and may require unique methods for processing parts, handling and storage. All of these factors, plus others, should be considered when evaluating whether it is cost effective to use a commercial part or not.

As an example, we will evaluate a few of the more basic cost factors such as cost of repair and cost of establishing and maintaining an inventory. Perhaps just these few costs will give us some indication of the magnitude of the total cost involved.

It will help to first make some assumptions. Let us accept the MIL-HDBK-217 statement that a high-reliability standard part is twenty-five times more reliable than a commercial part. To be realistic, we will reduce this factor to 10 to 1, since all standard parts will not be of the high-reliability type. A rough estimate of a weapons system trainer is that it may include 50,000 parts. Suppose, we assume also that only 1/10 of these presently military type parts become commercial parts and each of these parts are used 2½ times/device, making a total of 2,000 different items. Average part cost will also be taken as $1/part for commercial parts and $3/part for military type parts.

Some other standard cost figures that we may use are: $200/item entry cost into the federal inventory, $150/item/year inventory maintenance cost and $20/hr. labor cost.

We also will assume that a standard part fails once every ten years. Therefore, with the assumed failure rate, we would have ten failures of the commercial part, or one per year. The cost of the commercial failed parts would be 5,000 parts x 1 failure/yr x 10 yrs x $1/part or $50,000. The military part would cost 5,000 parts x .1 failure/yr x 10 yrs x $3/part or $15,000. Labor costs for ½ hr/repair of commercial parts would be 5,000 x 1/year x 10 yrs x ½ hr x $20 hr = $500,000, while it would be only 1/10 as much or $50,000 for the higher reliability military type part.

The difference in inventory cost would be even greater. This is because there is really no requirement to maintain any inventory on any commercial part that has an interchangeable military type. One of the primary benefits of standardization is really to stock only those items with the most applications in order to decrease the variety of items that must be maintained in inventory. Therefore, using our prior assumptions, as applied to 2,000 different types of parts that would not be in inventory if military parts were used, we find that we have burdened the government with 2,000 parts x $200/part entry + 2,000 x $150/yr x 10 yrs = $3.4 million over a 10 year life cycle.

The difference in cost for just these few considerations is a whopping $3,885,000 over a 10 year period.

We will grant that different assumptions can be made and different results might be obtained. However, our interest is merely to illustrate a few of the costs of some necessary government support functions that are normally not included by suppliers when evaluating military type parts versus commercial part cost factors. More functions could be evaluated, but just these few illustrate what a tremendous amount of tax dollars are at stake.

Qualification Testing

The objective of using military type parts is to attain higher reliability, greater durability, and maximum versatility. Characteristics enhancing these objectives are designed into military type parts and the parts are then subjected to extensive qualification testing to assure that they comply to these required design characteristics. Unfortunately, this testing is expensive and the cost must be added to the cost of the part. Contractors must, therefore, pay a little more to get the assurance that the part has better quality, dependability and performance. Prior testing of commercial parts varies and it can be inconsistent, limited to selected characteristics and usually is not conducted by an impartial and independent testing laboratory.

Delivery Problems

Another objection to military type parts is the extended delivery time. Delivery could take two to three times that required for commercial parts. Six months is not considered abnormal; however, this does not apply to all parts. The contractor's procurement people already know which types of parts require extended delivery times and measures can be taken to design in and procure the long-lead items early in the procurement cycle. Problems should only occur when design changes

must be made and new parts ordered or when requests for waivers to use nonstandard commercial parts are submitted for approval too late in the life of the contract. Preliminary in-plant testing is expected to cause some design revisions, but delays in submitting the RFW's should not occur and can be very costly to the contractor.

Suppression of Innovative Design

The American manufacturer has long been characterized as being ingenious and expected to use innovative ideas in his designs. Commercial parts manufacturers claim that standardization and the requirements to use military type parts suppresses the contractor's ability to be innovative. These requirements may delay the innovative designer, but should not suppress his ingenuity. Innovative parts can always become qualified as "Standard" parts, but it does take some extra effort for specification writing and testing. Manufacturers frequently fail to recognize that there are advantages to being listed on a qualified product list. The delay and difficulties encountered by conscientious contractors is recognized by the DoD and solutions are being sought to shorten the cycle between drawing board and QPL. Some of the more promising approaches will be explained later in this paper.

Part Obsolescence

An advantage of military type parts that is mentioned only occasionally is that they are much less likely to be declared obsolete and no longer available as replacement parts. Sources of supply of commercial parts are frequently limited or sole source. The government is often left without a source when a small manufacturer goes out of business or just decides that a model is no longer profitable to produce. Commercial parts also tend to be unavailable as direct replacements as time progresses. Several generations of a particular commercial part can come into existence in a ten year span. What started as minor improvements can progress to the point where the eventual part only slightly resembles the original part. Direct part for part interchangeability then becomes difficult. When replacement parts are no longer interchangeable or become unavailable, the government inventory procuring activity is not equipped to make a major redesign effort to accept substitute parts. It then becomes necessary to take the system out of operation, send it to a contractor and issue a contract to redesign, refurbish, and modify the device to accept presently available parts. True, refurbishment is necessary at some time, but obsolete commercial parts hasten the time when this becomes necessary. It is not unusual to pay almost as much to modify/refurbish a device as it originally cost.

Part Warranties

An approach under consideration is to have commercial parts manufacturers offer warranties on their products. Surely, it is suggested, a warranty is better than a qualification test. This option may be easily applied in private industry, but not in the government where it is very difficult to control and can be very expensive in time and money. To begin with, out of the 50,000 parts mentioned before, possibly a maximum of 500 could be parts where a manufacturer's warranty may be applicable. Some of these may have warranties and some may not. Warrantied parts must be clearly marked or users will not even be aware that the parts can be returned for repair. The time cycle for removing the parts, making out paperwork, sending the part back to the manufacturer, and possibly waiting months for the repaired part to wend its way back through the necessary channels will tempt local maintenance crews to attempt local fixes. This will cause unnecessary repair costs (although unauthorized) and could result in loss of warranty due to tampering. Even if strict orders prevented this, what incentive is there for the manufacturer to observe a fast turnaround. An extended return cycle can only be countered with an extra quantity of spares on hand. This again would result in increased cost to the government.

Present Trends

Many activities are presently seeking the optimum approach to the military versus commercial parts question. The government is open to suggestions and trying to be flexible. To begin with, many commercial subsystems are already being used. The requirement for computers and peripheral equipment had a lot to contribute to this trend. The government recognized that such equipment is undergoing almost daily change. Improvements are being made literally overnight. It was a case of accepting a costly outmoded design or buying an item that represented the latest state-of-the-art, possibly at a significant cost savings. Each item (or subsystem) of considerable value is now evaluated in light of total cost and its ability or potential for being supported. The government is considering training, provisioning, tools and test equipment, maintainability, inventory expense, manuals and handbooks, the support process

itself, and the availability, qualification and cost of personnel. This evaluation concept has resulted in a significant increase in commercial type equipment being used in training devices. Major assemblies or subsystems can support separate provisions for manuals, training and support, but individual components such as integrated circuits, resistors, switches, lamp assemblies and other assorted items can not.

The sister Military Parts Control Advisory Groups (MPCAG) set up by the DoD offer great promise in several areas. The more senior organization, the Defense Electronics Supply Center (DESC) has made many contributions in the coordination and preparation of specifications, arranging QPL tests, reviewing requests for waivers and attempting to make the process of using military type parts easier, quicker, and more consistent. The other MPCAG, the Defense Industrial Supply Center (DISC) has until recently concentrated on hardware and fastening devices, but is now widening its vistas to include other mechanical type items. DESC has considerably shortened the evaluation process in reviewing requests for waivers. Individual telephone inquiries can provide same day service. A list of ten to twenty items will generally require only five to seven days for a written response with recommendations. DESC does not restrict their recommendations to only military type parts. They recommend "preferred" type parts. These could be preferred commercial parts, selected from the available nonstandard type parts, or preferred military type parts where several military types are available. Their experience in reviewing specific parts and their excellent staff of specialists in various categories have resulted in activities of all three services using the same preferred high quality parts. Where there is a demand for a commercial part and no standard exists, DESC will prepare a specification and coordinate the necessary arrangement for QPL certification. This has significantly shortened the time cycle for converting many nonstandard parts to standard military type parts.

The proposed MIL-STD-965 is another case where the DESC has taken steps to assist the contractor. It proposes that a preliminary conference be held very early in the contract life between representatives of the contractor, DESC, and the procuring activity to establish which types of proposed parts will be acceptable and which types should be avoided. This removes much of the uncertainty on the part of the contractor on which types of parts should be used, which are available and which will require long lead times. This early clarification of parts criteria will possibly avoid some later redesign or reprocurement costs.

MIL-STD-749 is the standard document used to detail how a contractor can request a waiver to use a nonstandard part. This document specifies all kinds of extra requirements and added costs to the contractor if he wants to use a nonstandard part. The full application of MIL-STD-749 could cost the contractor more to use a nonstandard commercial part than to use an approved military type part. The emergence of the MPCAG's has allowed DoD activities to accept the MPCAG recommendation without requiring the preparation of full specifications and test data. The submission of a page from a vendor's catalog is frequently sufficient for approval since DESC or DISC is usually familiar with the part and its characteristics.

We may eventually see manufacturers submitting their commercial products to a government activity for preparation of specifications, testing, and qualification. Testing costs will probably still be borne by the manufacturer and will be similar for competitive products. Specification costs may be borne by the government for items meeting some established criteria. Alternate sources of supply must continue to be encouraged for obvious reasons.

The application of Logistic Support Analysis to some of the more recent contracts offers an interesting new source of data that may be helpful in future comparisons of military versus commercial parts.

There is no doubt that lack of data makes an evaluator more cautious and the inclination is to resist change and stick with what is familiar - in this case, military type parts. Therefore, it has been usual practice to specify the military parts and make the manufacturer supply the burden of proof that a commercial part is completely adequate for the application. New data on repair time, frequency of repair, labor costs, tool costs, and inventory costs will now become available on reparable items from LSA data. Some of the mystery of cause and effect of commercial parts will be removed.

Conclusion

Commercial parts will make an ever increasing contribution to the simulation industry. This industry demands innovations and commercial parts provide a

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flexibility to meet these needs that does not exist in all military type parts. Commercial parts are usually less expensive to procure, some effectively provide functions not available in military type parts, and they will always be the technical leaders in advanced designs.

There are advantages and disadvantages to military type parts just as well as there are to commercial parts. We can not afford to disregard standard parts or ignore commercial parts. There is a proper place for each, but we must find out which one fits which niche. My concern is primarily to make you and other decision makers conscious of the need to consider all facets before any expensive mistakes are made. Private industry, the government and all of us as taxpayers, can ill afford costly errors of judgment at this time.

Much work still remains to be done. The guesswork must be eliminated and the evaluation process simplified. We need better data, new guidelines and procedures, life cycle costing criteria, better controls on and knowledge of part applications and universal industry standards for commercial parts.

It's going to take a concerted effort by the government and private industry. Work groups and committees must be established to develop facts, data, and direction and new policies implemented. It can't be done by individual activities or companies. It affects too many people, too many operations, and too much money. It must be done initially at the policy level.

The government is very fortunate that many commercial parts are available and functionally comparable, and in many cases interchangeable with military type parts. Commercial parts will always have a market and the government will be part of that market. The government's share of the market is growing and will continue to grow. Some commercial parts can almost be considered as standards now, others may never meet the criteria for government use. However, if a commercial part is good enough and used in enough applications, it will eventually evolve into a military type part and this should happen a lot quicker in the future than it does now.

ABOUT THE AUTHOR

MR. FRANKLIN W. ROZELL has been the standardization administrator at the Naval Training Equipment Center for the past four years. As such, he is charged with the responsibility for coordinating the review and evaluation of all contractor requests for waivers to use nonstandard parts as well as developing and maintaining a standardization program compatible with NAVTRAEQUIPCEN, Navy and DoD policy and requirements. He is a practicing maintenance engineer and is currently also the value engineering program manager. He has worked for the Navy for the past 14 years, the last 12 for the Naval Training Equipment Center. His previous experience has included 13 years in private industry as buyer, production engineer, design engineer, and field service representative to the U.S. Navy. Mr. Rozell received his M.S. degree in management from Rollins College and his B.E. degree from Syracuse University. He has taken courses at Lehigh University, Adelphi University, and attended various DoD-sponsored courses. He is a member of the Society of Logistics Engineers and has served in several executive positions in the Society of American Value Engineers.

A PROGRAM FOR INCREASED FLIGHT FIDELITY IN HELICOPTER SIMULATION

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Abstract

Increased emphasis has been placed on the need for and usefulness of major aviation training devices - flight simulators. A description of a modern trainer and the status of current simulation is provided. High fidelity is necessary to achieve high training transfer to the aircraft. The authors describe the need for and a proposed basic approach to technical simulator flight testing designed to achieve high fidelity. Ideas were formulated as a result of the authors' participation in the development and validation of the SH-2F Weapons System Trainer, Device 2F106. NAVAIRTESTCEN participates in the program as a technical advisor on flight fidelity. Major contributions are aircraft testing for the establishment of criteria data followed by simulator evaluation, both performed by engineering test pilots and flight test engineers. These evaluations used established and disciplined flight test techniques and should be commonplace in the development and validation of flight trainers. An extensive table of criteria data tests is provided for reference. Typical instrumentation tables for both the aircraft and trainer are included. Specific comments are made concerning trainer testing problems and the priorities of tests. A discussion is included on simulator data-gathering techniques, appropriate parameters, and equipment needed. Finally, the scope of a visual system evaluation is presented, along with a description of its usefulness in additional testing of the basic trainer.

Background

The Department of Defense has proposed a procurement effort of over $800 million on flight simulators in the next 2 years (reference 1). This represents a resurgence of military interest in simulators spurred on, in part, by the fuel shortage of 1973. Prior to that, the airlines and NASA had made significant advances in flight simulation. The reduced cost of training in a simulator has often been presented as justification for its procurement. Other arguments are based on the increased amount of training made possible with a training device when compared with the limited aircraft assets available. The potential for regular 16-hr days in active training in the simulator causes quantum jumps in command productivity. However, the most dramatic result from the addition of a simulator such as the SH-2F Weapons System Trainer (WST), Device 2F106, is in the improved quality of training. Response to emergency situations, some of which are not practical for actual flight, can be learned and practiced in a high fidelity simulator. Realistic tactical military situations that are often impossible to establish in actual flight during peacetime can be encountered. The high fidelity of the performance and flying qualities of the device is essential to the realism required to adequately train for these missions.

There is a stigma associated with all flight trainers due to the varying degrees of poor fidelity provided by many. Grand claims and limited practical utility of even the most expensive trainers have led to repeated disappointments. Nevertheless, simulated flight time has been authorized as a substitute for actual flying experience. Concurrently, actual military flight time has, in many cases, been severely reduced. If the desired readiness is to be maintained, these new trainers intended to replace actual flight time must be capable of providing high training transfer. Increased flight fidelity is necessary to obtain this high transfer. Skills learned and practiced in a trainer can only be applied directly to the aircraft if adequate fidelity exists with the aircraft characteristics. A high fidelity flight trainer offers the potential for a variety of additional applications, such as accident investigation, the development of improved operational procedures, or the evaluation of proposed aircraft modifications. As a specific example, research such as the evaluation of new shipboard approach lighting could be economically accomplished in a validated high fidelity trainer. The utility of such a device is in many ways limited only by its availability and the imagination of the user.

Purpose

Generally speaking, the procurement of major aviation training devices should be treated similarly to that of new aircraft. Specifically, the use of established and disciplined flight test techniques should be commonplace in the development and validation of these devices. The simulator manufacturer must be prepared to demonstrate predetermined levels of trainer fidelity with the aircraft data. Time, procedures, and necessary equipment must be planned into the development program to accomplish this goal. Airframe and aircraft subsystem manufacturers should be informed and responsive to the needs of the simulator manufacturers for specific design data and equipment. This requirement is often concurrent with development/production of the aircraft systems, due to the desire to use the trainer as the aircraft is introduced operationally. Significant coordination and cooperation, not to preclude commercial contracts, are required if the needs of the service are to be met. The purpose of this paper is to describe the need for and a proposed basic approach to technical simulator flight fidelity testing.

The proposed approach included here was formulated as a result of the authors' participation in the development and procurement of the SH-2F WST, Device 2F106. The program, completed in November 1976, produced exceptional flight fidelity for the Navy's first modern helicopter flight trainer and is being used at the Rotary Wing Aircraft Test Directorate as a guideline for future work. Selected data illustrating the fidelity obtained are presented in appendix A. Photographs of the trainer are contained in appendix B. Presently, a CH-46E Operational

Flight Trainer (OFT) and an SH-3H OFT are active projects with anticipation of RH-53D, CH-53E, and LAMPS MK III trainers in the future.

Navy Trainer Procurement Team

The NAVAIRTESTCEN team is part of a larger group organized to ensure the success of a new trainer. A brief overview of the major participants in a Navy procurement follows. NAVAIR is charged with funding and overall program management. Close coordination is established with the Naval Training Equipment Center (NAVTRAEQUIPCEN), where a contracting officer and a program engineer are assigned. The program engineer provides working-level management of the acquisition. A Fleet Project Team (FPT) is assigned by the Office of the Chief of Naval Operations (OPNAV) through the appropriate operational commanders. This team usually consists of instructor pilots and aircrew from the eventual using activity such as the specific type training squadron. These individuals provide the invaluable contribution of current fleet experience with the particular aircraft. In the past, these pilots were erroneously expected to become instant experts on flying qualities and performance (FQ&P) evaluating. Today, in addition to extensive systems verification and qualitative flight testing, the FPT has the prime respon[illegible] for directing the development of the instruc[illegible]face system based on its intended training requi[illegible]

The eventual recipient of the trainer is the Fleet Aviation Specialized Operational Training Group (FASOTRAGRU). This organization is responsible for facility management, maintenance, and operational readiness of the device in support of the using activity. NAVAIRTESTCEN participation involves, as a minimum, a test pilot and engineer team to act as technical advisor to NAVAIR and the Program Engineer (NAVTRAEQUIPCEN) on FQ&P. The contractor team generally consists of a program manager, computer specialists, and various systems specialists including an aerodynamicist.

NAVAIRTESTCEN Policy

The general guidelines for NAVAIRTESTCEN participation were established in coordination with NAVTRAEQUIPCEN and NAVAIR and are contained in reference 2. The major elements of that instruction are:

a. Establish liaison with the appropriate NAVAIR and NAVTRAEQUIPCEN personnel.

b. Provide assistance during specification preparation, proposal evaluation, and source selection phase.

c. Monitor the contractor's development.

d. Provide NAVAIRTESTCEN developed flight test data for incorporation in the trainer specification, for contractor baseline data, and as the standard for measurement of simulation fidelity.

e. Review math model, criteria report, and Acceptance Test Procedures and comment on their applicability.

f. Conduct Navy Preliminary Evaluations (NPE's) as required.

g. Participate in government in-plant acceptance tests.

h. Provide engineering and test pilot assistance in adjusting hardware and software programs to achieve proper flight fidelity.

i. Participate in government on-site acceptance tests.

j. Participate in validation of subsequent trainer units during in-plant and on-site acceptance.

k. Conduct periodic follow-on tests and evaluations to assess the effects of design changes.

l. Prepare reports of flight fidelity evaluations for distribution to NAVAIR, NAVTRAEQUIPCEN, and the training device contractor.

The policy contained in this instruction has been successfully applied to several fixed-wing and rotary-wing programs. NAVAIRTESTCEN participation is best utilized from the earliest evolutions including preparation and review of requirements, proposals, and specification documents through final acceptance.

Typical Milestones

The usual milestones of an acquisition program for a training device are included here for general information. This description applies when NAVTRAEQUIPCEN acts as the procuring activity; in some situations, NAVAIR acts directly as the procuring activity. A document defining an operational requirement is generated in OPNAV. Interested parties are convened by NAVAIR and NAVTRAEQUIPCEN to produce a document entitled "Military Characteristic," which specifically describes the features that would be required to accomplish the desired mission. After receiving authorization from NAVAIR, NAVTRAEQUIPCEN creates a detailed specification and solicits proposals from interested contractors. Source selection is based on the evaluation of these proposals. A contract is made through NAVTRAEQUIPCEN with the selected manufacturer. The contract usually includes an integrated logistics support package and numerous deliverable data items, such as math model, design, data, facilities, and test procedures reports in addition to the trainer itself. Several NPE's precede the in-plant acceptance of the device. Government in-plant acceptance tests are conducted on the complete system to determine if it is ready for fleet delivery. Following this acceptance, the device is disassembled, relocated at the designated training facility, and reassembled. Government on-site acceptance testing is conducted prior to formal acceptance of the trainer. Following this final acceptance, specific hardware and software changes continue throughout the useful life of the trainer to improve it and maintain a comparable configuration with the fleet aircraft. Annual verification of trainer fidelity is also conducted.

Modern Trainer Description

Modern trainers such as Device 2F106 are characterized by an exact replica of the cockpit and crew station containing functional and, in some cases, actual aircraft

equipment. Flight control, navigation, communications, and weapons systems are modeled in addition to most other aircraft systems. A full 6-deg-of-freedom motion base is hydraulically powered and driven by computer-generated commands. Some fixed-wing trainers meet their requirements with less than the 6-deg-of-freedom motion system; however, helicopter and other Vertical Takeoff and Landing (VTOL) applications specifically use this full-motion system to adequately simulate low-speed flying qualities. A full range of aircraft vibrations for normal and emergency situations adds to the simulated environment as a result of the programmable motion system. Sound systems electronically generate air-rush, rotor, engine, and accessories' noise into the cockpit. Various types of visual systems can accurately present spatial information to the pilot. Moving targets, such as ships and other aircraft; functional lighting systems, such as glide-slope indicators and strobe lights; and detailed geographic features are routinely included in visual scenes. Instructor stations provide interactive displays and dedicated controls for manipulation of mission configuration, malfunctions, environment, and communications. Instructor-assistance features normally include demonstrations, exercises, checkrides, audio recordings, ground-track displays, and automatic initialization capabilities.

Subsystems and assistance features are linked together and function simultaneously in real-time via the digital computation system. Simulated aircraft systems, trainer systems, environmental programs, and executive programs create great demands on the general-purpose digital computer. The flight dynamics program is very extensive and is the major concern in improving flight fidelity. Numerous other systems are cued from the flight dynamics program, including all instruments, the sound and motion systems, and the visual system. Flexibility must be designed into this program in order to later refine the FQ&P fidelity. Computational speed and accuracy, particularly for the flight dynamics program, are imperative if satisfactory flight fidelity is to be attained. Iteration rates of 16 or 20 Hz appear to be the minimum acceptable for this purpose.

The complete operational flight envelope of the aircraft can and should be simulated with high fidelity. This eliminates training restrictions and allows the trainer to be used for various mission-related tasks. In some cases, simulation should go beyond the normal flight envelope, for example, the demonstration of departure characteristics (fixed-wing) or blade stall (helicopter).

Flight Data Requirement

An extensive data base is required to ensure that the level of fidelity is sufficient throughout the flight envelope. In the past, Navy test programs did not produce sufficient mid-envelope aircraft data for trainer development. Sophisticated data collection systems now generally employed for new aircraft testing have reduced this problem. However, a requirement for additional aircraft flight testing in support of the trainer development has been the general rule. This is particularly true when dealing with an older in-service aircraft that may have undergone evolutionary changes in design. Past reliance on wind-tunnel and theoretical stability data and uninstalled engine performance data has resulted in marginal fidelity. In helicopter simulation, the classical aerodynamic solutions are not as well defined as in fixed-wing aircraft or rocket-powered vehicles. In general, the data requirements for trainer development are classified into two categories: design data and criteria data. Design data are required elements such as weight and balance, cockpit layout, structures, wiring logic, fuselage and rotor system physical characteristics, wind-tunnel estimates, moments of inertia, etc. Much of this type of data is commercially available to the simulator manufacturer. Criteria data are generally those provided by NAVAIRTESTCEN through test and evaluation.

A typical matrix of criteria data tests is presented in appendix C. The presentation includes a list of required tests, appropriate data presentations, and specific comments. This is a general outline intended to be modified as necessary to meet the needs of a specific aircraft configuration or mission. The data base should be extensive enough to provide parameter isolation as much as economically possible. This procedure will allow simulator program changes to be less random, more effective, and more timely. Due to the detail of simulation, it is necessary to obtain data that interrelate systems such as the rotor, engines, flight controls, and airframe. The most obvious example would be in slow-speed, low-altitude flight characteristics where the environment, performance, and flying qualities interrelate significantly. This may be the most challenging area of helicopter simulation due to its mathematical complexity. Criteria data should be gathered for each system simultaneously in order to establish proper relationships in the simulation.

Flight test data must be extensively documented. Known factors, such as aircraft configuration, gross weight, CG, pressure altitude, air temperature, wind, and all normal flight test parameters, must be identified for each test. When repeating the test in the simulator, these factors are assigned values as recorded during the aircraft test. In this manner, variables between the aircraft and simulator tests are minimized and data obtained are comparable.

Aircraft Testing

The aircraft testing necessary to provide these criteria data should be done using standard flight test techniques (references 3 and 4) by a trained test pilot. It is highly desirable to have the same team perform both aircraft and simulator evaluations. This assignment policy ensures maximum efficiency in technique and data transfer, as well as flexibility in further testing that may be required. In addition to these advantages, criteria data provided by a government agency such as NAVAIRTESTCEN are objective and not influenced by specification guarantees and design goals. Simple "hand-held instrumentation" and "kneeboard-recorded data" provide flexibility in assessing several aircraft. This method is particularly useful for mechanical characteristics and some static tests. However, the required precision of flight test data demands much more reliable and in-depth technical data gathering. Significantly improved flight fidelity requires a serious effort to obtain detailed criteria data, particularly in flight dynamics. For instance, time histories of angular acceleration and rate

are more useful than the resultant attitude. An instrumented aircraft of the appropriate configuration is necessary. A typical instrumentation package is detailed in appendix D, table I. The aircraft should be provided early in the program so that data may be obtained, processed, and provided to the contractor without causing program delays. These data may then be incorporated in appropriate documents such as the criteria report and acceptance test procedures. In this manner, the standards for acceptance will have been established for the simulator evaluations to follow.

Simulator Testing

Evaluation of the training device for FQ&P fidelity should be accomplished by a trained test pilot using standard flight test techniques as in the aircraft. This has seldom been done in trainer programs except by NAVAIRTESTCEN in accordance with its current policy. It is in sharp contrast with most previous programs in which the trainer manufacturer selected the appropriate data and determined the test methods which were then accomplished by the contractor or the FPT. Today, the trainer evaluation is nearly identical in scope to that of the aircraft as presented in appendix C. A very large portion of the effort is devoted to control-response testing and validation of the flight dynamics. In some tests, limitations to standard procedures are encountered due to an incomplete environment, i.e., the lack of a visual system when attempting visually referenced test methods. In this case, modified procedures need to be developed to provide the information usually obtained from visual reference. If possible, the modified test techniques should be evaluated in the aircraft and test results compared with those from standard test techniques. An example of this problem is encountered in lateral-directional statics while attempting steady-heading sideslips. In this test, a visual reference is customarily used for turn rate. The turn-needle presentation to the pilot can also be used; however, it is not nearly as accurate as a properly planned visual reference. In the simulator, turn rate is computed very accurately. This more precise value can be displayed on the instructor's console. With some coordination, turn rate as displayed can be included in the now combined scans of the test pilot and instructor and used as the quality factor for the data point as in the aircraft. Other examples of modified techniques include using Doppler readouts of drift angle and ground speed for establishing precise hover or translation sideward, rearward, or slow forward for trimmed-control positions. On simulations without Doppler, the display of orthogonal velocities on the instructor's console would suffice. Altitude hold features of the aircraft or the use of a single parameter freeze capability in the trainer assist in obtaining in-ground effect (IGE) data points where pilot workload may be excessive without a visual reference. Doppler information or velocity readouts can also be used for vertical climb performance tests when a visual reference is not available. It is hard to imagine a case where digital or analog information could not be monitored real-time to compensate for unavailable cues during tests. These particular problems need to be identified early and appropriate solutions planned for.

During simulator testing, evaluators must be prepared to recognize pilot adaptability to the flying qualities of the simulator. This is likely to occur when performing a unique task such as hovering and when other cues are not available. A pilot can quickly develop the necessary scan and technique to perform a precise task, overcoming gross fidelity deficiencies. Other contributing factors are the potential for many hours of flight time in the simulator while concentrating on a single problem area and the lack of recent aircraft flight time for the test pilot while at the contractor's facility for extended periods. To combat the latter, arrangements should be made, if practical, for concurrent aircraft flight time while the pilot is assigned to the trainer program. However, quantitative tests should be designed wherever possible to minimize reliance upon qualitative assessments that may be influenced by incorrect or incomplete environments.

Pilot performance and qualitative opinion have been observed to markedly improve with the addition of major subsystems that provide motion, aural, and visual cues. This is a testimony of their necessity in training, but a caution that during evaluations their absence or uncorrected false cues may affect test results. A subtle example of this type of problem occurs when using the visual display for a ground reference, but the effects of a more limited field of view such as increased workload are not considered. The need for qualitative testing remains significant, but more attention to test design is required in the trainer than in the aircraft if the results are to be meaningful. The assistance of the FPT pilots should be stressed when considering qualitative tests. Specific debrief by the NAVAIRTESTCEN team may lead to definition of problems and quantitative testing based on their observations.

One area where only qualitative simulator flight testing is presently being done is in the evaluation of the motion system. Criteria data for vibration characteristics are used, but the final tuning remains qualitative. Engineering tests are being conducted to evaluate the response characteristics of the system and its individual servoactuators. The results confirm the mechanical quality of the motion system but have no direct relationship to its effect on the simulator pilot. Currently, there are more than a dozen different sets of algorithms in use for motion system integration to the simulator flight dynamics. NASA and NAVTRAEQUIPCEN are working toward optimization in this area. Several other studies are underway to determine the suitability of motion systems for providing onset cues. Speculation ranges from the elimination of motion systems altogether to using them for static attitudes while providing onset cues with a controlled seat device. Research on this subject should prove highly beneficial. The strong interrelationship between motion and visual cues and their importance in flying helicopter-VTOL-type aircraft requires close evaluation of their respective system performance.

A building-block approach is necessary to establish a logical test sequence. Early evaluations may be restricted to a few operational systems. In general, the following priorities should be established. Test instrumentation must be calibrated and all sources of data output verified. This includes validation of all normal cockpit instrumentation. Next, control system mechanical characteristics should be established. At this point, standard aircraft checklists provide appropriate test procedures for basic cockpit evaluations. Static

performance and flying qualities necessarily must precede dynamic evaluation and adjustment. This same build-up approach should be applied to basic airframe characteristics followed by increasing levels of AFCS compensation. Motion system checks should be performed next, followed by visual system validation. Extensive testing should be devoted to mission-related tasks at the conclusion of this sequence. These priorities are not intended to limit the conduct of evaluations. However, consideration must be given to the total effect of changes made, including the validity of any results previously obtained.

Simulator Data

A number of specific data-gathering techniques have been established for the simulator. Aircraft test conditions can and should be matched exactly for each test in the trainer. The capability to instantaneously stop the computer update of selected parameters or all flight dynamics leads to what has been termed a "freeze" function. By the judicious use of "freeze" and the preestablished and recallable "initial condition" function, the process of data gathering can be dramatically accelerated. In addition to cockpit data, preselected parameters can be digitally presented on the instructor's Cathode Ray Tube (CRT) display to provide essentially on-board instrumentation. Line printers or x-y plotters, if part of the installation, may be used to provide hard copy of CRT-displayed data or could be programmed to plot static data. For dynamic data in helicopter simulators, there is a need for multiple channels of analog data. As a minimum, control positions, attitudes, rates, and accelerations are required. Individual parameters should be verified to be suitable for comparison to the aircraft data. For example, control positions should be monitored at the same location as in the aircraft. Inherent lags in the aircraft control system are not accounted for if the simulator control parameters are provided from the rotor system module. The channels need to be accessible through a single terminal board wired to the digital-to-analog converters. Analog recording devices are connected to this terminal for real-time simultaneous display of each selected parameter. Immediate analysis of program modifications can often be provided with this setup. A simple utility program for simultaneous calibration of all channels has proven to be a great time saver. For automated data processing later by the computer facilities at NAVAIRTESTCEN, a tape-recording system can be simultaneously connected to the same terminal. A summary of typical trainer "instrumentation" is presented in appendix D, table II.

If properly planned and programmed, the outputs of these simulator monitoring systems can provide comparable data format to that provided by any airborne instrumentation used. Identical paper speeds and parameters scaling are obviously necessary for direct comparison of data. Early consideration must be given to the characteristics of parameters when selecting data format, i.e., when attempting modifications to acceleration onset in tenths of a second, the minimum desirable paper speed is 10 mm per second. With these systems, it is possible to monitor sufficient parameters to isolate individual problems and determine the effects of changes. What results is an iterative process to correct/improve the fidelity of specific parameters. Aircraft data should be available and organized in a ready reference system for immediate access. Sufficient time must be given to analysis of appropriate data to provide an engineering approach to progressive changes. Development sessions quite often require the NAVAIRTESTCEN team to provide testing and evaluation expertise in support of the contractor. These government-supported development efforts should be limited in duration and scheduled only after the contractor has made sufficient progress with his own capabilities to warrant it. Specific milestones should be jointly established by the contractor and government representatives as a prerequisite to this type of effort.

Evaluations to determine progress and current status of the fidelity, such as NPE's and acceptance tests, must be conducted on a fixed configuration. No changes should be made during these evaluations, since all effects due to the change may not be immediately obvious. For example, changes to accessory loads for rotor engagement and disengagement characteristics may seem isolated, but autorotation performance is directly affected. All test results in the simulator must be identified to a specific software configuration. It is essential that the contractor provide this information and adhere to rigid administrative procedures to control and document program changes and reassemblies. It is equally as important for the evaluators to adequately identify and catalog the voluminous amount of data generated.

Reporting Procedures

Deficiencies must be formally reported as they are discovered. Current policy is for the program engineer to collect, organize, and prioritize all Discrepancy Reports (DR's) on standard forms provided by NAVTRAEQUIPCEN. A single master log of these reports is thereby maintained. For technical deficiencies, it is necessary to provide, as part of the DR, copies of appropriate data to fully describe the problem. DR's are furnished to the contractor immediately for corrective action. Following each evaluation, or as appropriate, NAVAIRTESTCEN submits reports directly to NAVAIR by message in Project Situation Report format. These reports are temporary by design and describe the latest documented status. Final documentation of the trainer's flight fidelity is provided by NAVAIRTESTCEN by formal report.

Visual System

Of particular interest, is the evaluation of visual systems. It is important to recognize that the visual system dramatically illustrates basic program weaknesses, as well as its own. As in the aircraft, visual cues are overriding to the pilot. Unstable visual presentations are capable of nauseating pilots within minutes as a result of the strength of the visual cue. Visual systems can be made to accurately track the host program and still not be suitable for training. In this case, modifications to the basic trainer program are required. It is best to start visual system integration only after the basic program has been brought to a reasonable level of fidelity and has been well documented. Experience has shown that trainers intended to have visual systems should not be accepted on the assumption that visual system integration will not require basic program modifications. Evaluation logically begins with the

installation. Independence of the visual system from motion system inputs, shielding of projectors, and simple cockpit "light leaks" need to be checked. The scene content can then be addressed. This includes verification of designed runway layouts, targets, ships, landing pads, lighting systems, etc., for accuracy and detail in each scene. Individual display shading and intensity should be evaluated concurrently with scene content. Registration is the term applied to alignment of a multiple window visual presentation and is essentially a spherical geometry problem. The effect of a horizon sloping in a forward presentation while level in a sidelooking presentation can cause pilot disorientation. Synchronization applies to the coordination problem resulting from a multiple visual computer installation when the scan rates of input data are not identical. The perception of this problem occurs in turns (for a side-by-side installation) as an alternating shift in scene content by the two displays. Both registration and synchronization should be carefully evaluated.

Static alignment and attitude checks are normally done as part of the visual systems normal maintenance check. However, dynamic accuracy is necessary if the system is to be considered satisfactory for training. A calibrated signal representing visual attitude in each axis must be established. This signal should originate as close to the actual display as possible. By displaying simulator attitude and visual attitude on the same recording device and performing single-axis control inputs, visual dynamic response can be quantitatively evaluated. Control inputs should consist of both reversals and steps. Attitude displacement is easily compared. System lags are presented as the response delay measured between simulator and visual attitudes. The time lag which must be minimized is made up of simulator computation, data transfer, visual system computation, and display requirements. Minimum lags are necessary to preclude pilot-induced oscillations, particularly while attempting to perform closed-loop tasks such as hovering. Simulator response to control inputs should have previously been validated so that testing is now directed toward the visual system fidelity.

After the visual system is validated, it may be used as a tool for further evaluating and improving specific areas of the flight dynamics program. In general, these areas relate to ground reference maneuvers such as takeoff, landing, and autorotation. The evaluation of ground-handling characteristics requires the use of a visual system. Landing gear reactions, steering, braking, turning, and skidding are each considered. Many mission-related tasks, such as shipboard approaches and landings, can now be evaluated. Extensive qualitative tests should be performed using all scenes, multiple maneuvers, and specifically employing each means of problem control. This is necessary to ensure that the various modes and controls do not affect the fidelity of the presentation. In particular, scenes that present relative motion, such as between a moving ship and the aircraft, or ship motion due to sea state that feeds back to the aircraft, must be closely evaluated. Minor control logic differences or nonmatched update rates can cause very significant problems that are not evident without the visual system.

Because of the strength of visual cues, it is important to consider the planned trainer mission when deciding on the FOV to be presented. Ultimately, an identical FOV to that of the aircraft is desirable. Until such time as the state-of-the-art can provide this capability, a trainer limitation is being created. In helicopter trainers, the absence of the lower few degrees of FOV is very serious. Normal vision cues used for precise hovering and landing are not present. Pilot compensation must be made by interpreting distance cues. This can be done on shore-based scenes or large-deck ship scenes, but it is impossible on small-deck ship scenes where the entire deck may be out of view due to "window" location. In general, VTOL/helicopter trainers should be provided with maximum coverage in the lower segments of FOV. Tradeoffs, if necessary, should be based on well-defined mission needs. Flight testing should be conducted to optimize window location. Various configurations of restricted FOV should be evaluated for effects on pilot workload.

Conclusions

The renewed interest in flight simulators is based on their potential to reduce costs while increasing the amount and quality of aviation training. High fidelity flight simulators are necessary if the desired training transfer is to be achieved. The approach to trainer development and validation presented in this paper led to the accomplishment of that goal in the SH-2F WST program. The basic concept of this approach is that flight trainers should be evaluated like aircraft by engineering test pilots and flight test engineers. Extensive criteria data must be provided from an instrumented aircraft of the appropriate configuration. Testing of the aircraft for criteria data and of the trainer for fidelity should generally follow the program outlined in this paper. Engineering evaluation of the trainer data is mandatory if the advantages of this program are to be realized. The test techniques used during the trainer evaluation should be identical to those used in the aircraft. In those cases where limitations to normal testing occur, modifications must be designed to provide comparable data. Trainer evaluators readily adapt to deficient simulator flying qualities. Tests designed to produce quantitative results minimize this problem. In addition, concurrent aircraft flight time is highly recommended. The effects of major subsystems such as motion, sound, and visual must be carefully considered when determining test sequence. A trainer data plan that includes output techniques and recording devices is a basic element of this approach.

The comparison of trainer and aircraft flight test data when properly analyzed provides an engineering approach to trainer software adjustments. The result of this process is a flight trainer that exhibits the FQ&P characteristics of the aircraft. The benefit derived is a flight trainer usable throughout the aircraft envelope that is limited only by its availability and the imagination of the user.

In the future, government requirements for trainer fidelity will undoubtedly become more stringent. A program such as described in this paper will receive wide acceptance and result in increased testing performed on trainers to meet that goal. Manufacturers of trainers would be aided by this program by receiving more definite guidelines, specific criteria data from current flight tests, and simulator flight test data on which to base modifications. As flight dynamics research

continues and math modeling and simulator implementation improve, the iterative testing and modifying currently necessary would be reduced. The ultimate justification would then be a vastly improved trainer at minimal development cost.

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APPENDIX A

Selected Data

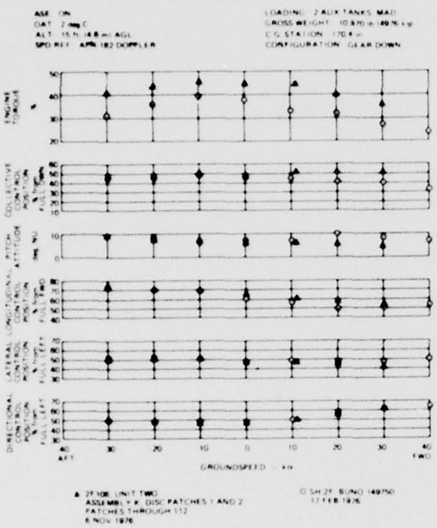

Figure 1
Low-Speed Trimmed Control Positions

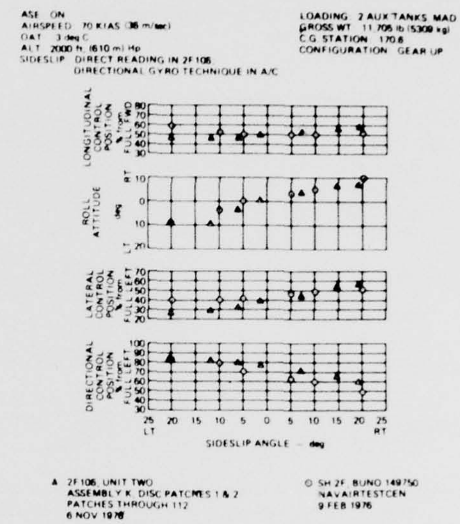

Figure 3
Static Lateral-Directional Stability

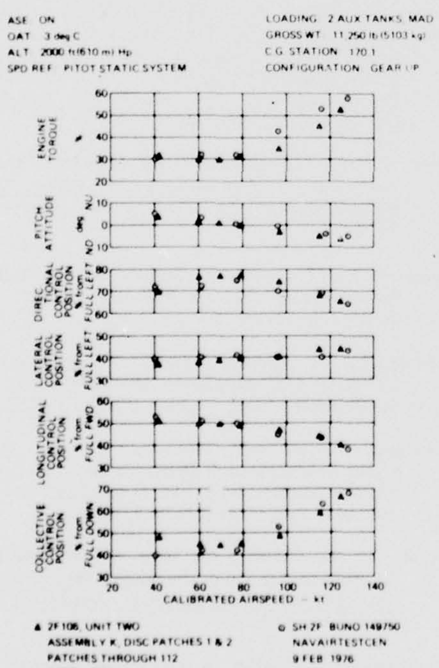

Figure 2
Forward Flight Trimmed Control Positions

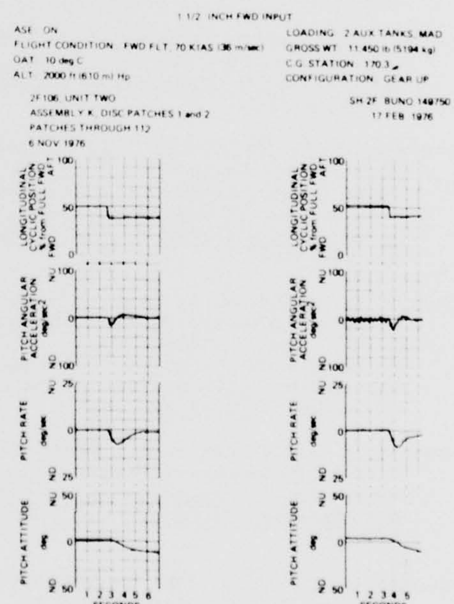

Figure 4
Pitch Axis Control Response

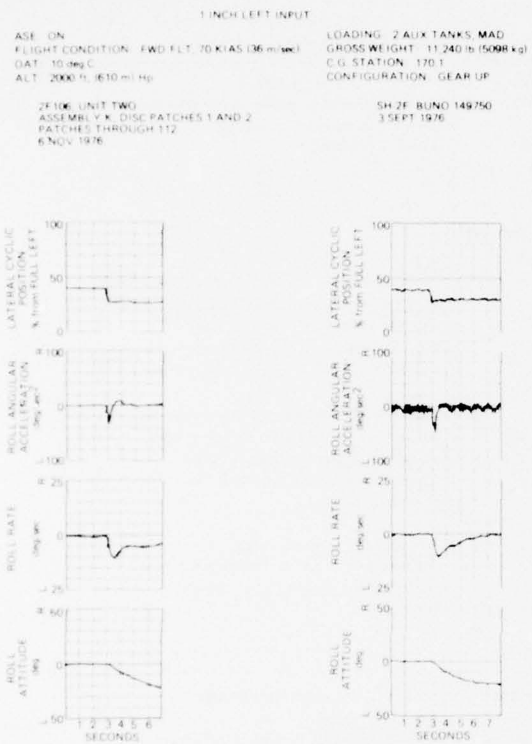

Figure 5
Roll Axis Control Response

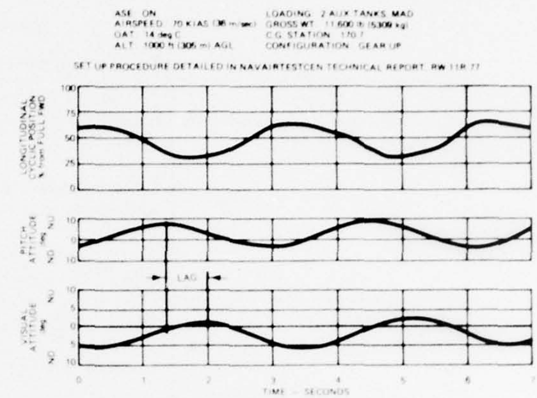

Figure 6
Dynamic Visual System Response

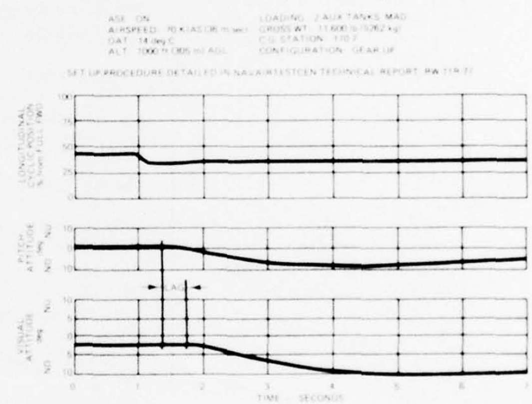

Figure 7
Dynamic Visual System Response

APPENDIX B

Photographs

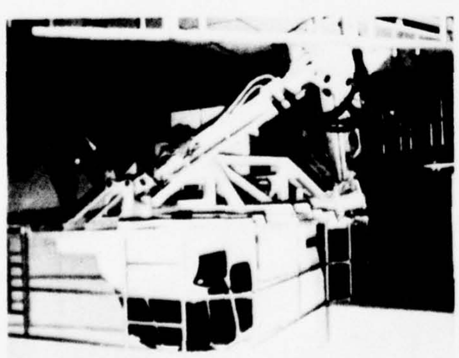

Figure 1
SH-2F Weapons System Trainer
Device 2F106, Unit One
NAS Norfolk, Virginia
March 1976
Prior to Visual System Installation

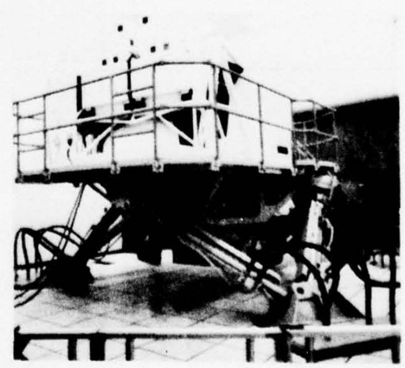

Figure 2
SH-2F Weapons System Trainer
Device 2F106, Unit One
NAS Norfolk, Virginia
July 1976
Visual System Installed

APPENDIX C

Tests for Establishment of Criteria Data in Aircraft and Simulator

Test	Data Presentation	Remarks
Weight and Balance	Gross weight Longitudinal, lateral and vertical CG CG variation with fuel burnoff Static aircraft attitude	Verify aircraft loading configuration.
Control System Mechanical Characteristics	Total control travel Control free play Breakout forces Control force gradients and hysterisis Control centering Trim system lags and trim rates Control system dynamics Control system coupling	Control system mechanical characteristics should be determined on several aircraft to get a good data base. Pilot qualitative comments on boost or hydraulic system-off control displacements and force gradients should be recorded. Trim rates should be determined as a function of control travel to check linearity.
Engine Start/Stop Rotor Engagement/Shutdown	Time history of throttle position, engine torque, rotor torque, rotor speed, turbine inlet temperature, gas generator speed and fuel flow	Use video tape coverage (with voice) of pilot going *through turnup and shutdown* checklists. Qualitative comments on gage/instrument movement/ function should be recorded for each affected system.
Ground-Handling Characteristics	Control positions and pitch attitude during ground taxi for specific ground speed, wind speed and direction and surface elevation Pwr increase to start taxiing	Primarily, qualitative comments on ground taxi/turning/braking characteristics.
Hover Performance	Hover attitude and control positions Rotor and engine power versus gross weight Collective control position versus gross weight Radar altitude versus engine torque IGE/engine torque OGE Rotor power versus engine power Time history of control positions, attitudes, and rates for pilot workload analysis	Data required for both OGE and IGE hover heights. Similar conditions (including available cues and identical tasks are required in trainer and aircraft.

Test	Data Presentation	Remarks
Slow Speed Performance and Flying Qualities		
Sideward Flight	Control positions, roll attitude, and engine torque versus paced ground speed	Precise measurement of paced ground speed and wind speed and direction required. Critical azimuth data should be obtained during steady winds of approximately 10 kt and 20 kt (5.1 m/sec and 10.2 m/sec).
Rearward/Slow Forward Flight	Control positions, pitch attitude, and engine torque versus paced ground speed	
Critical Azimuth	Control positions, pitch and roll attitudes, engine torque and wind speed versus relative wind azimuth	
Vertical Climb Performance	Rate of climb versus engine torque Collective position versus engine torque	Record engine torque required to hover OGE before commencing climb. Use torque increments above this value.
Airspeed/Altimeter Calibration	Airspeed position error for level flight, climbs, and descent Altimeter position error for level flight	
Engine Performance		
Test Cell Data Power Checks	Corrected engine shaft horsepower, corrected gas generator speed, corrected fuel flow, corrected specific fuel consumption versus corrected turbine inlet temperature	
Engine Dynamics Selected throttle movements covering full range of control Response to trim system actuation Response to automatic load sharing system operation	Time history of throttle position, engine torque, rotor speed, fuel flow, gas generator speed, and turbine inlet temperature	From time histories determine lags, overshoots, scheduling, static and transient droop.

Test	Data Presentation	Remarks
Level Flight Performance and Trimmed Control Positions	Referred rotor power versus referred true airspeed for a full range of referred gross weights (can also use nondimensional presentation) Individual rotor power versus calibrated airspeed Ratio of main rotor power to engine power versus calibrated airspeed Control positions, pitch attitude, sideslip, and engine torque versus calibrated airspeed	Data should be collected for ball-centered flight. The effects of sideslip on power should be determined. Drag increments should be determined for configuration changes (*i.e.*, *external* stores, door/hatches open, etc.). Data should be combined with slow speed performance data to form three dimensional power required curve.
Climb and Auto Performance and Trimmed Control Positions	Rate of climb and descent versus calibrated airspeed Control positions and pitch attitude versus calibrated airspeed	
Power Effects	Control positions, pitch attitude, and cockpit vertical velocity versus engine torque	
Static Longitudinal Stability	Longitudinal stick force, stick position, and pitch attitude versus calibrated airspeed	Power fixed at given trim condition.
Dynamic Longitudinal Stability		
Short Term	Time history of angular acceleration, load factor, rate and attitude response to control doublet, and pulse inputs	From time histories, determine period, frequency and damping of oscillation or time to half (double) amplitude.
Long Term	Time history of pitch attitude and airspeed response to slow and fast starts	Trainer tests should be conducted on motion to induce effects of control inertia and/or dynamics.
Static Lateral-Directional Stability	Control positions, bank angle, ball position, rate of descent, and indicated airspeed versus sideslip	Use steady heading sideslip test technique.

Test	Data Presentation	Remarks
Dynamic Lateral-Directional Stability		
Lateral and Pedal Control Doublets and Pulse Inputs	Time history of control positions, angular accelerations, rates, and attitudes	From time histories, determine period, frequency, and damping of oscillation or time to half (double) amplitude.
Cyclic and Pedal Only Turns	Time history of control positions, rates, and attitudes	
Spiral Stability	Time history of bank angle	
Release from Steady Heading Sideslips	Time history of control positions, sideslip, heading, yaw rate, roll attitude, roll rate, and airspeed	
Maneuvering Stability Constant Altitude Constant Power	Longitudinal stick force and stick position versus load factor or bank angle	Document control force relieving functions if applicable, and account for this feature in test procedure.
Control Response Step Control Inputs	Time history of control positions, angular accelerations, rates, and attitudes. Also, present load factor and airspeed (except hover) for longitudinal inputs and load factor for collective inputs. Minimum data to include hover, normal cruise, and fast cruise for multiple sized inputs	Emphasize overlaying aircraft and simulator time history control response data for comparison. Note maximum acceleration/rate, time to reach maximum acceleration/rate and initial acceleration/rate lag to control step input. Document cross coupling resulting from single axis control step inputs. Document basic airframe characteristics and repeat for each appropriate mode of AFCS operation.
Autorotational Flying Qualities		
Auto Entry	Time history of control positions, throttle position engine torque, rotor speed, attitudes, and rates	Control fixed until rotor speed decay or attitude change requires recovery.
Full Autos Power Recovery	Time history of control positions, throttle position, engine torque, rotor speed, rates, attitudes, sideslip, airspeed, ground speed (Doppler), pressure altitude, radar altitude, and load factor	Record wind speed and direction during test.
R/D Parameter Isolation		Determine effect of rotor speed, sideslip, and bank angle on rate of descent during autorotation from cockpit gauges.

Test	Data Presentation	Remarks
Vibration	Vibration amplitude versus frequency for given condition (airspeed and loading) Also amplitude versus calibrated airspeed for given frequency	Record vibration data for pilot and copilot station for all flight regimes.
Stall	Stall boundary as a function of airspeed, rotor speed, density altitude, and loading condition	Qualitative comments on vibration and attitude response to stall and control sequencing required to reduce/aggravate the condition.
AFCS Evaluation	Document pilot workload required for identical tasks under each mode of AFCS operation Repeat appropriate tests under each mode of AFCS operation	Design tests to evaluate each mode of the AFCS.

APPENDIX D

Table I.

Instrumentation
SH-3H BuNo 148977

Parameter	Characteristic	Recording Device (1)	Output Device (2)
Longitudinal Cyclic Pos.	Percent from Full Fwd	Data Tape Recorder/Pilot	Cockpit Indicator
Lateral Cyclic Pos.	Percent from Full Left	Data Tape Recorder/Pilot	Cockpit Indicator
Dir. Pedal Pos.	Percent from Full Left	Data Tape Recorder/Pilot	Cockpit Indicator
Collective Pos.	Percent from Full Down	Data Tape Recorder/Pilot	Cockpit Indicator
Tail Rotor Pitch	Deg	Data Tape Recorder/Pilot	Cockpit Indicator
Pitch Attitude	Deg Up or Down	Data Tape Recorder	Attitude Gyro
Roll Attitude	Deg Left or Right	Data Tape Recorder	Attitude Gyro
Yaw Attitude	Deg Left or Right	Data Tape Recorder	Directional Gyro (Self-Caging)
Pitch Rate	Deg/Sec Up or Down	Data Tape Recorder	Rate Gyro
Roll Rate	Deg/Sec Left or Right	Data Tape Recorder	Rate Gyro
Yaw Rate	Deg/Sec Left or Right	Data Tape Recorder	Rate Gyro
Pitch Ang. Accel.	Deg/Sec^2 Up or Down	Data Tape Recorder	Angular Accelerometer
Roll Ang. Accel.	Deg/Sec^2 Left or Right	Data Tape Recorder	Angular Accelerometer
Yaw Ang. Accel.	Deg/Sec^2 Left or Right	Data Tape Recorder	Angular Accelerometer

Parameter	Characteristic	Recording Device[1]	Output Device[2]
Load Factor	g	Pilot	Computed
Sideslip	Deg Left or Right	Data Tape Recorder/Pilot	Cockpit Indicator
Radar Alt.	Ft	Data Tape Recorder/Pilot	A/C Gauge (Rad. Alt.)
Ground Speed	Kt	Data Tape Recorder/Pilot	A/C Gauge (Doppler)
Drift Angle	Deg	Data Tape Recorder/Pilot	A/C Gauge (Doppler)
Turn and Slip	Needle and Ball Pos.	Pilot	A/C Gauge
Vertical Velocity	Ft/Min	Pilot	A/C Gauge
Airspeed	Kt	Pilot	Cal. A/C Gauge
Torque (1 and 2)	Percent	Pilot	Cal. A/C Gauge
Altitude (Baro.)	Ft	Pilot	A/C Gauge
OAT	Deg, C	Pilot	Cal. A/C Gauge
Time	Sec	Pilot	Hand-held Stopwatch
Wind	From Deg Mag/Vel, Kt	Pilot	Hand-held Anemometer or Tower Report
N_R	Percent	Pilot	A/C Gauge
N_f (1 and 2)	Percent	Pilot	A/C Gauge
N_g (1 and 2)	Percent	Pilot	A/C Gauge
T_5 (1 and 2)	Deg, C	Pilot	A/C Gauge
Gross Weight	Lb	Pilot	Computed
Fuel Load Front Center Aft	Lb	Pilot	A/C Gauge
External Stores	Loaded/Unloaded	Pilot	As Selected
Long. CG	In.	Pilot	Computed
T/R Power	Ft-Lb	-	(Ref. Data)
M/R Power	Ft-Lb	-	(Ref. Data)
Control Force	Lb	Pilot	Hand-held Force Gauge
Fuel Flow	Lb/Min	-	(Ref. Data)
Event Marker	Step Signal	Data Tape Recorder	Cockpit Control

NOTES: (1) Engineering units tape will be created from FM tape in aircraft instrumentation package. Computer plotting will be done where applicable.
(2) Equipment indicated is special instrumentation unless identified as aircraft equipment.

APPENDIX D

Table II

Instrumentation
Device 2F64C

Parameter	Characteristic	Recording Device (1)	Output Device (2) (3)
Longitudinal Cyclic Pos.	Percent from Full Fwd	Analog Recorder/Instructor	Console Page
Lateral Cyclic Pos.	Percent from Full Left	Analog Recorder/Instructor	Console Page
Dir. Pedal Pos.	Percent from Full Left	Analog Recorder/Instructor	Console Page
Collective Pos.	Percent from Full Down	Analog Recorder/Instructor	Console Page
Tail Rotor Pitch	Deg	Analog Recorder/Instructor	Console Page
Pitch Attitude	Deg Up or Down	Analog Recorder/Instructor	Console Page
Roll Attitude	Deg Left or Right	Analog Recorder/Instructor	Console Page
Yaw Attitude	Deg Left or Right	Analog Recorder/Instructor	Console Page
Pitch Rate	Deg/Sec Up or Down	Analog Recorder/Instructor	Console Page
Roll Rate	Deg/Sec Left or Right	Analog Recorder/Instructor	Console Page
Yaw Rate	Deg/Sec Left or Right	Analog Recorder/Instructor	Console Page
Pitch Ang. Accel.	Deg/Sec^2 Up or Down	Analog Recorder	-
Roll Ang. Accel.	Deg/Sec^2 Left or Right	Analog Recorder	-
Yaw Ang. Accel.	Deg/Sec^2 Left or Right	Analog Recorder	-
Load Factor	g	Pilot	Computed
Sideslip	Deg Left or Right	Analog Recorder/Instructor	Console Page
Radar Altitude	Ft	Analog Recorder/Instructor	Console Page
Ground Speed	Kt	Analog Recorder/Instructor	Console Page
Drift Angle	Deg	Analog Recorder/Instructor	Console Page
Turn and Slip	Needle and Ball Pos.	Instructor	Console Page
Vertical Velocity	Ft/Min	Instructor	Console Page
Airspeed	Kt, Observed Kt, Calibrated	Pilot Instructor	A/C Gauge Console Page
Torque (1 and 2)	Percent	Instructor	Console Page
Altitude (Baro.)	Ft	Instructor	Console Page
OAT	Deg, C	Instructor	Console Page
Time	Sec	Pilot	Hand-held Stopwatch
Wind	From Deg Mag/Vel, Kt	Instructor	Console Page
N_R	Percent	Instructor	Console Page
N_f (1 and 2)	Percent	Instructor	Console Page

Parameter	Characteristic	Recording Device (1)	Output Device (2)(3)
N_g (1 and 2)	Percent	Instructor	Console Page
T_5 (1 and 2)	Deg. C	Instructor	Console Page
Gross Weight	Lb	Instructor	Console Page
Fuel Load Front Center Aft	Lb	Instructor	Console Page
External Stores	Loaded/Unloaded	Instructor	Console Page
Long. CG	In.	Instructor	Console Page
T/R Power	Ft-Lb	Instructor	RMM
M/R Power	Ft-Lb	Instructor	RMM
Control Force	Lb	Pilot	Hand-held Force Gauge
Fuel Flow (1 and 2)	Lb/Min	Instructor	RMM

NOTES: (1) Analog Recorder wired directly to computer D/A output source for on-scene analysis. FM data tape recorder connected to same source for making engineering units tape (as required) at NAVAIRTESTCEN CSD.

(2) Remote Memory Monitor (RMM) can be used to monitor any parameter in the program.

(3) All simulated instruments are calibrated and meet at least aircraft standards. Each gauge will be checked and verified against commanded computer value. Cockpit parameters may be taken from console page to eliminate gauge error and for simplicity.

ABOUT THE AUTHORS

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SECURE, MULTIPLE-SHIP OPERATIONAL EW TRAINING

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INTRODUCTION

It is now possible to perform realistic, multiple-ship area EW defense training for a task force of ships, or even a full fleet, without transmitting threat signals and without going to sea.

The principle involves the use of on-board threat simulators and radar target simulators which reproduce a full, dynamic multiple-threat environment and are controlled and synchronized from a single command position via narrowband radio links. The individual ships can be in port, or underway for reasons totally unrelated to EW training during the exercise. The simulators aboard each ship reproduce the signal and radar environment as it would be seen by that ship, including consideration of:

- All types of threats (ships, aircraft, missiles).
- Friendly emissions.
- Modulation and antenna scan characteristics of each signal reproduced.
- Range and azimuth of each threat relative to that individual ship.
- Appropriate changes in the modes of threat signals as functions of time and distance from the ship.
- Maneuvering of the ship on which the EW receiver and radar equipment is located.

A multiple-ship, multiple-threat simulation, such as that shown in simplified form in Figure 1

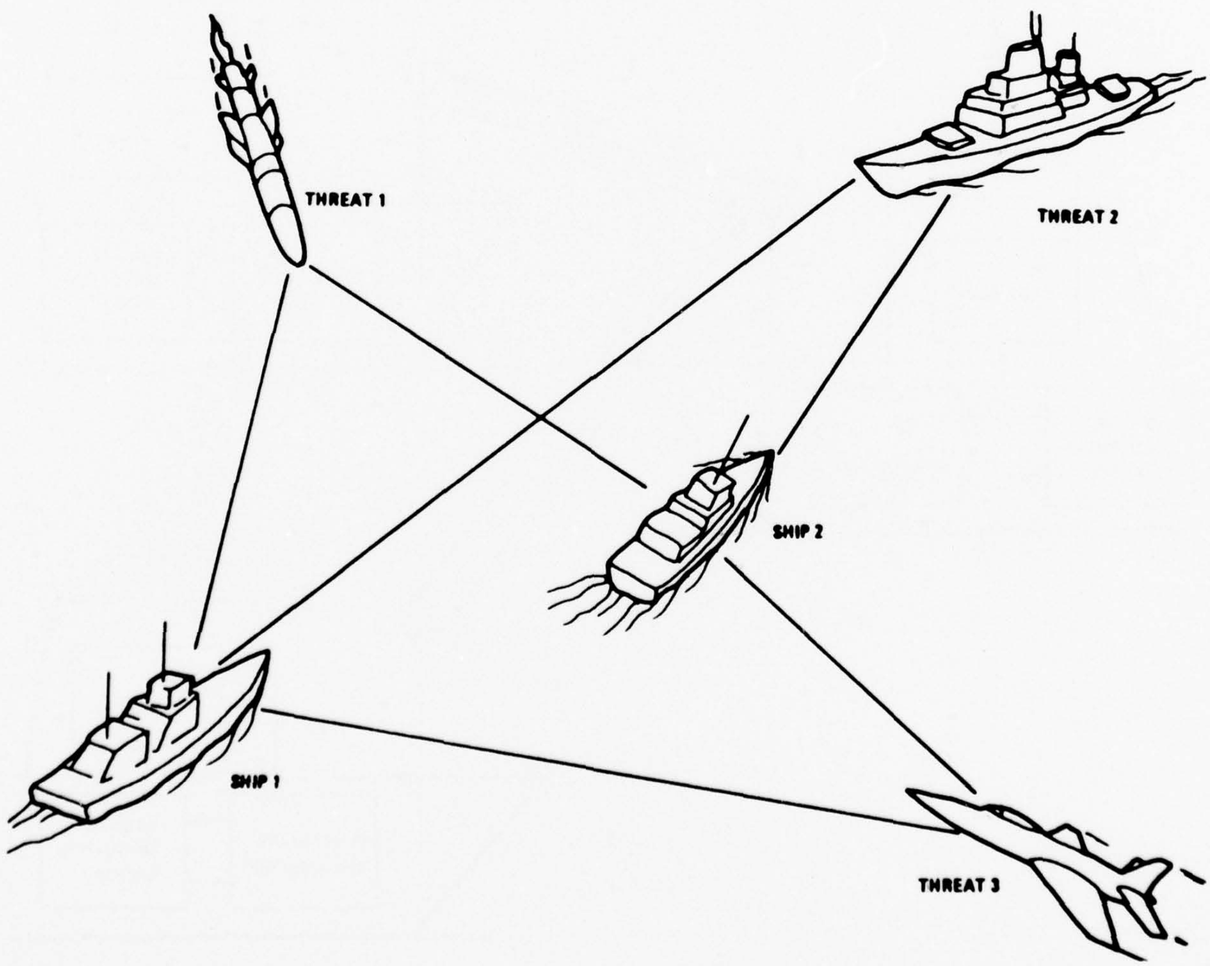

Figure 1. Relative Threat Position Diagram

is analyzed by a computer to yield the moment-by-moment signal environment from the point of view of each of the ships. The ships and threats are moved at realistic rates; and the signal environment is reanalyzed often enough to provide realistic dynamic performance on the displays of the EW equipment in the ships.

Naturally, the faster moving missile and aircraft threat signals must be updated more often than the slower moving ship related threat signals.

The computer then generates a simulator command cassette tape for use in each of the individual on-board simulators, with synchronizing file markers at preestablished points in the program to simplify later synchronization of the simulation on the individual ships.

The same steps are applied to the analysis of of the radar responses as seen by each ship, and the appropriate radar target commands are added to the threat signal scenario.

Each remote simulator then generates its output signals and displays in response to these commands using its own cassette tape player, so no threat signals need to be transmitted. Only control and periodic synchronizing signals for the tape players need be sent from the central control station. Since these signals are intrinsically narrowband and are formatted for full compatibility with any audio link, they can be easily sent over existing, secure ship-to-ship radio links, or over cables, or even commercial telephone circuits if desired. Further, since the control signals are not phase critical, they can be sent

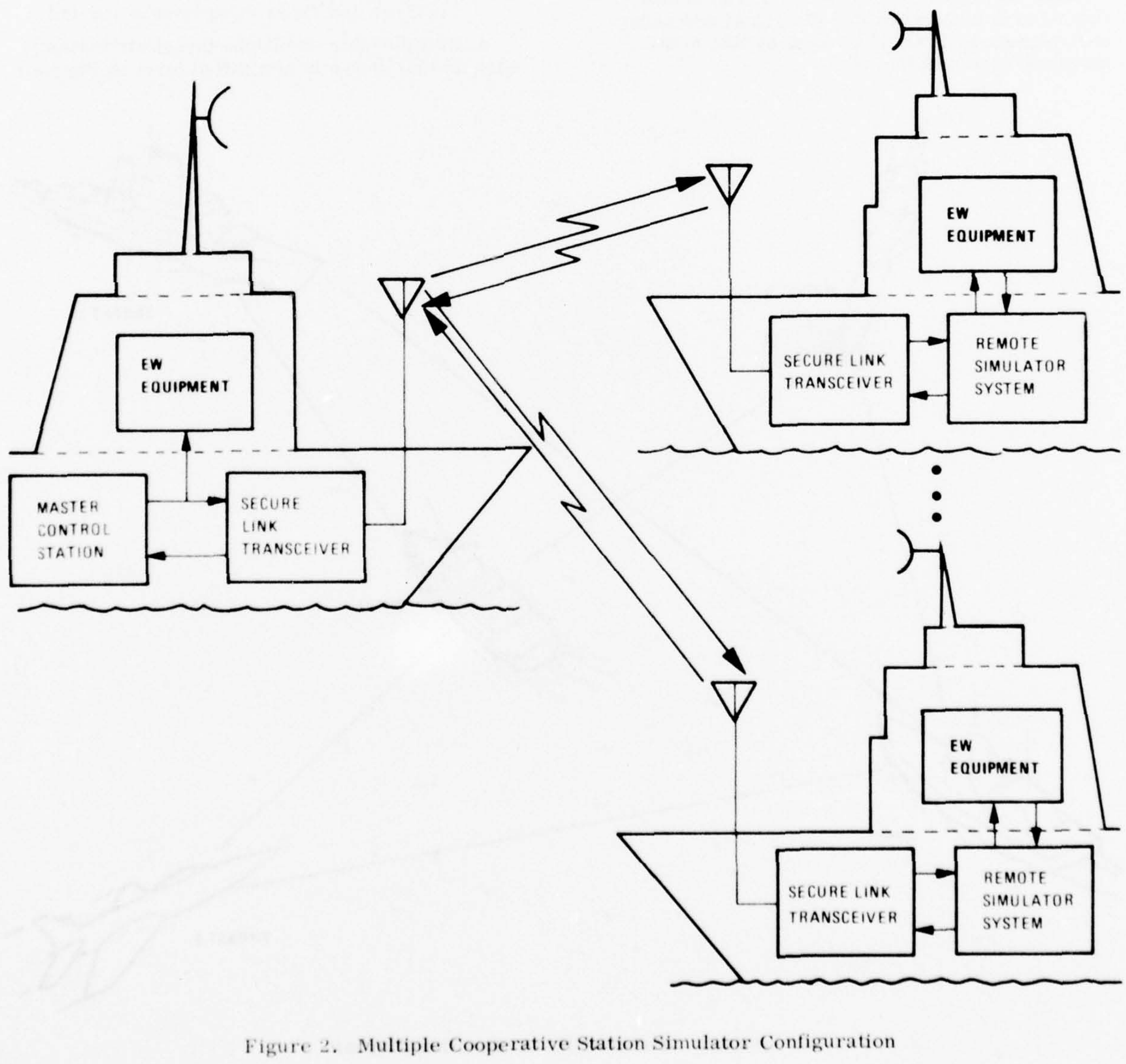

Figure 2. Multiple Cooperative Station Simulator Configuration

over satellite links to allow cooperative training of EW operators on widely separated ships without any performance degradation.

Because the threat and maneuver scenario seen by each of the participating ships reflects the same situation from different points of view, all are participating in the same exercise and can perform the normal operational reporting functions. If the full scenario is displayed to an instructor by a minicomputer (such as the AN/UYK-20) at the control station he can score the exercise in real-time by comparing the reported information and conclusions with the actual situation represented by the exercise scenario.

THE SIMULATOR SYSTEM

Figure 2 shows the full simulator system, including a single master control station and a number of remote simulator stations on-board individual participating ships. From this figure, it will be noted that two-way communication must exist between each of the participating ships and the master control station.

This allows use of a maximally efficient "non-redundant" command scheme by assuring that each command sent is received properly by its intended remote system (through an automatic acknowledgement technique). Also note that signals to remote simulator equipment on board the ship in which the master control station is located are connected to the command station by cables. As will be seen below, this technique does not require several dedicated links, but can use a single net frequency for the whole exercise; the same net can be used for voice communication (although somewhat degraded) in one of the operating modes.

MASTER CONTROL STATION

The master control station, as shown in Figure 3, comprises:

- A master control console on which the instructor plays a tape to control the cassette players at the remote simulators and to synchronize the scenarios. It also allows the instructor to make real-time changes to the scenario through keyboard commands.

- A link interface unit which converts the serial RS-232 output from the control console into a form that can be easily and accurately transmitted over any audio link.

There are two system operating modes which can be selected by the instructor, a narrowband mode and a wideband mode. In the narrowband mode, the master control console outputs data at 300 bits per second; only recorder control commands are passed to the remote simulator systems. These commands include:

- Start

- Stop

- Rewind

- Go to file number XX (100 file numbers available).

In this mode, the link interface unit outputs a narrow band On-Off keyed (OOK) signal at 3200 Hz. This signal is high passed, so that low-passed voice signals can be mixed with the control signals on the same voice grade link if desired. Because of the narrow bandwidth of the control signals in

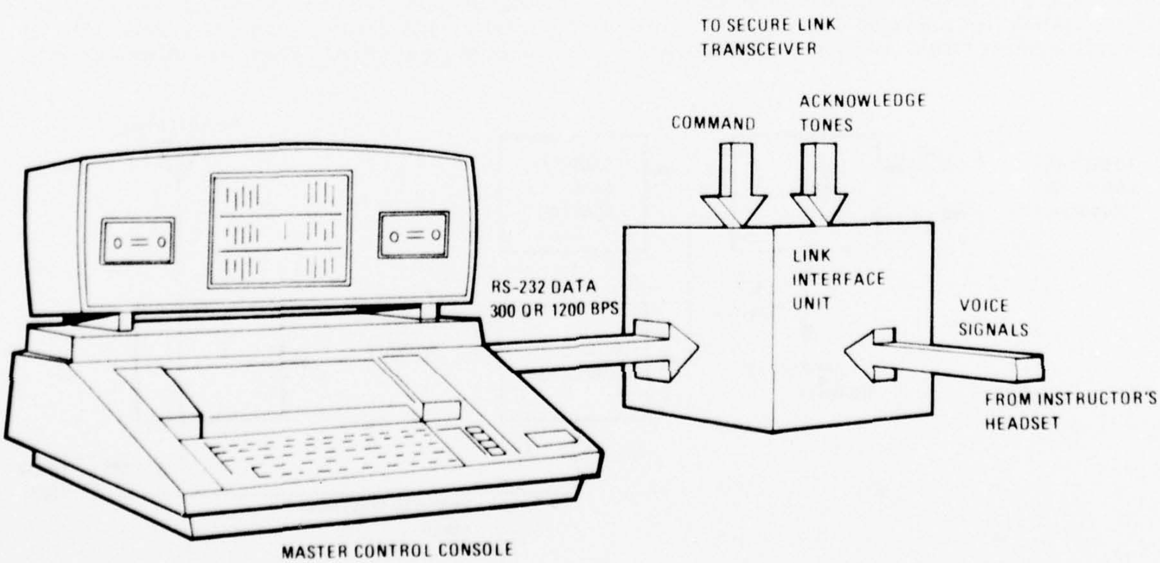

Figure 3. Master Control Station

the *narrowband mode, signals must be sent at a* very low rate (although adequate for control and synchronization of the scenarios) but the narrow bandwidth also allows the system to work to full performance even over very poor quality links. All of the actual signal parameter or target position data passed to the simulation equipment in the narrowband mode is stored on tapes at the remote locations.

In the wideband mode, the instructor (or an on-line *computer) can generate commands which* will directly alter the signal parameters output by the remote simulators. In this mode, the link interface unit converts the RS-232 serial data into a frequency shift keyed (FSK) signal for transmission to the remote simulators over the voice grade link. Since the FSK signal occupies most of the bandwidth of a voice grade channel, it cannot share the channel with voice signals as described for the narrowband mode.

Both modes *would probably be used during* any sort of training operation, but in a short term, highly dynamic problem (a battle scenario for example) the system would be in the narrow-band mode most of the time with the instructor switching into the wideband mode for brief periods to change some parameter for a specific reason. For longer term problems (for example, a medium activity, 24-hour problem) the wideband mode might be used most of the time with commands coming directly from an on-line computer to provide maximum *flexibility* to the problem.

In either mode the RS-232 data comes from the control console in serial form, and is collected by the link interface unit into formatted output words with synchronizing, address, and parity bits. When the command words are received by the remote simulator system or systems to which they are addressed, coded acknowledgement tones are sent back to the master station link interface unit. If no acknowledgement tone is received, the command *word is sent again until the proper answering* tone (identifying the addressed remote system) is received. If a command is not properly received and acknowledged within 5 seconds, the system notifies the instructor that one of the links is out. Since secure links often drop out suddenly with loss of synchronization of encrypters, this is an important feature of the system.

The design of the link interface equipment allows the system to operate accurately with *virtually any level of signal-to-noise ratio in the* communication links used to transmit and acknowledge commands. A degraded link will just require more and more repeated commands as the signal-to-noise ratio drops; but since multiple parity bits are checked, no false commands will be accepted by the remote systems. This creates a graceful degradation of performance with link degradation.

REMOTE SIMULATOR SYSTEM

Figure 4 is a block diagram of one of the remote simulator systems. The Link Interface Unit in this system receives and demodulates the FSK or OOK signals from the master control station, checks the parity bits to determine that the signal was correctly received, and sends a properly coded acknowledgement tone back to the master control station. It also separates the low-passed voice channel from the command signals if the system is in the narrowband mode.

In a narrowband operation, the control signals go to the cassette tape player which then controls the signal simulator. In wideband operation, signals are passed directly to the signal simulator to modify signal parameters.

The signal simulator subsystem generates large numbers of simultaneous signals which are coupled into the inputs of the shipboard EW equipment so that the equipment can receive both its normal input signals *(from its antennas) and the*

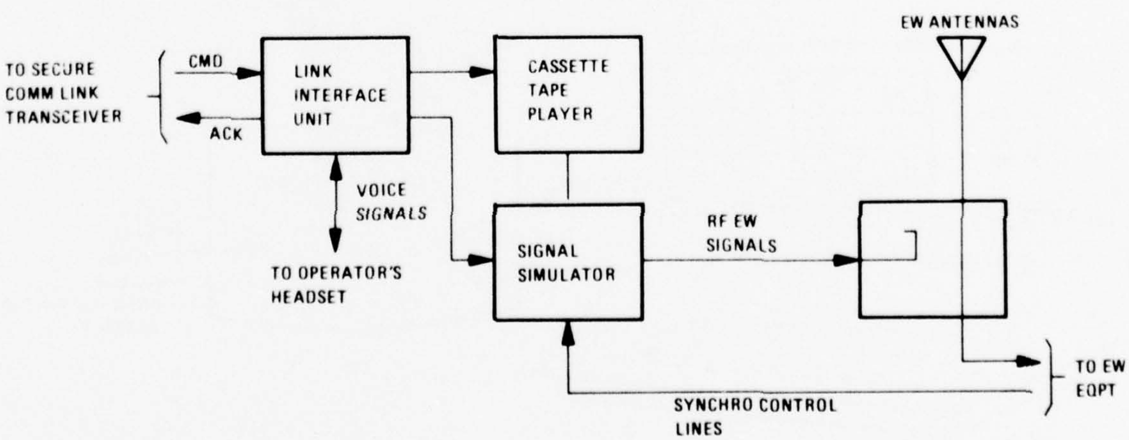

Figure 4. Remote Simulator System

simulated signals generated on board. The signal simulator also interfaces with the antenna control synchro system to provide realistic stimulation of the direction finding functions of the EW equipment. A third function performed by the signal simulator is the generation of the control signals required to display simulated targets on one or more radar PPI scopes.

SIGNAL SIMULATOR

The *signal simulator* portion of the remote systems actually generate the RF environment seen by the EW equipment and the return images of the radar PPI scopes on-board the individual ships taking part in the training exercise, as shown in Figure 5. It comprises pulse/scan generators, RF generator/modulators, an antenna simulator, and a radar target simulator. This subsystem is made up of standard GSA-listed simulation equipment very similar to that used in the 7B1 training facility at New London (see Figure 6) and in the 10A3 facility at Pearl Harbor (see Figure 7) which have been in use for over 5 years with a 98 percent availability record. However, these units will be selected from the newest product lines, which by use of new designs and components generate significantly higher density environments using fewer modules. They will also be from the 6000 series portable dynamic simulator hardware line to make them compatible with shipboard operation. (See Figure 8.) The whole subsystem is modular and can provide any desired signal density by the addition of equipment modules.

The pulse/scan generators create many pulse signals in response to the commands received from either the cassette player unit or the link interface unit. All signal parameters are stored in a dedicated memory circuit in each generator so commands need be given only to change parameters. Each generated signal has a unique pulse modulation and scan characteristic, but the signals are interleaved on a pulse by pulse basis, onto a single set of output lines. To allow the interleaved pulses to be sorted out by the other equipment in the simulator, a set of parallel current target address (CTA) lines are provided to identify each pulse with the signal to which it belongs.

The RF generator/modulators rapidly tune to the correct RF frequency for each of the signals on a pulse by pulse basis. The pulses are attenuated to provide the correct scan-related signal level for each pulse, and are also attenuated to simulate the effects of receiving antenna pointing. CW signals, if required, are generated in the RF generator/modulator subsystem and are independently modulated with the receiving antenna characteristics before being summed with the pulsed signals.

The receiving antenna attenuation factors are provided by the antenna simulator unit. It determines the antenna pointing angle by sensing the five-wire synchro control outputs. Since the correct azimuth of arrival of each of the simulated signals is stored in a memory circuit in the antenna simulator, it can calculate the angle "off-of boresight" for each pulse of a signal, and can apply the correct attenuation factor (including the effect of antenna sidelobes) to the control line from which the RF generator/modulators derive their information.

The radar target simulator accepts command data from the cassette recorder or link interface

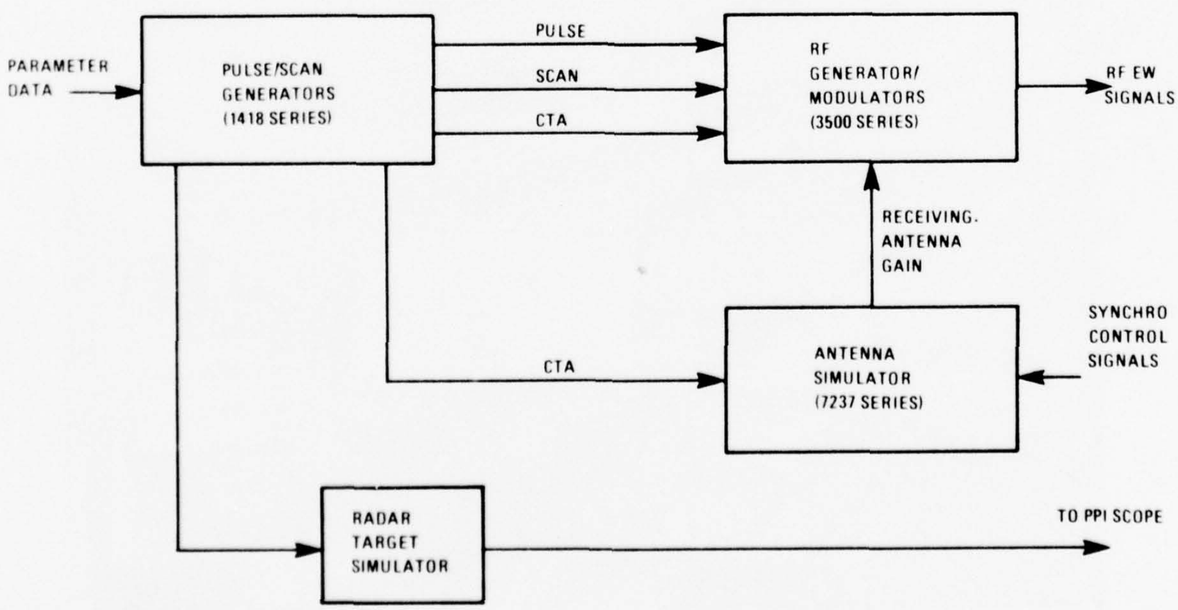

Figure 5. Signal Simulator

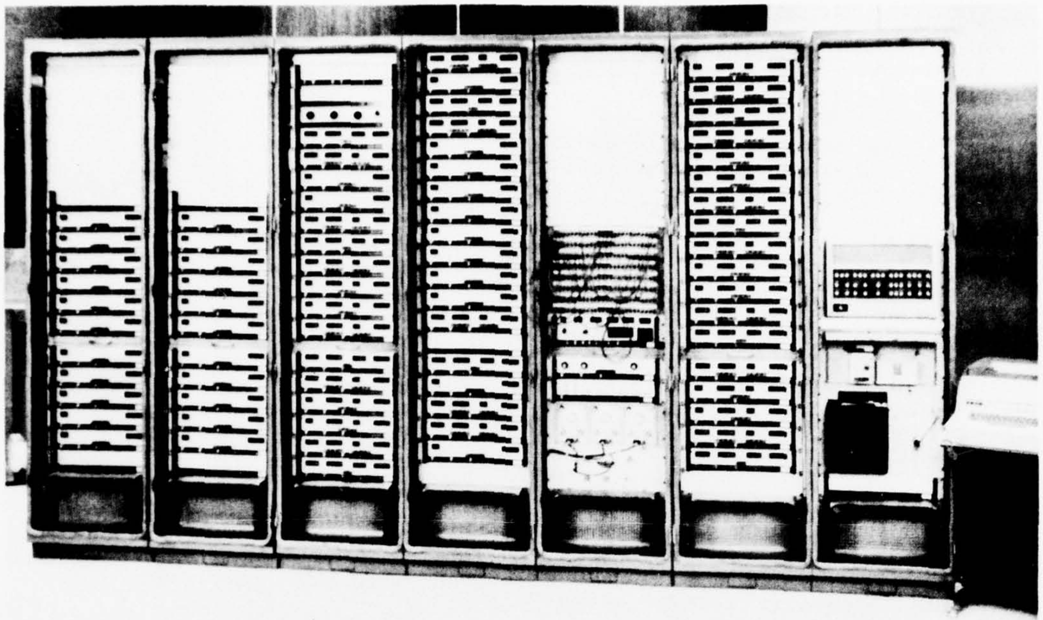

Figure 6. 7B1 Simulator

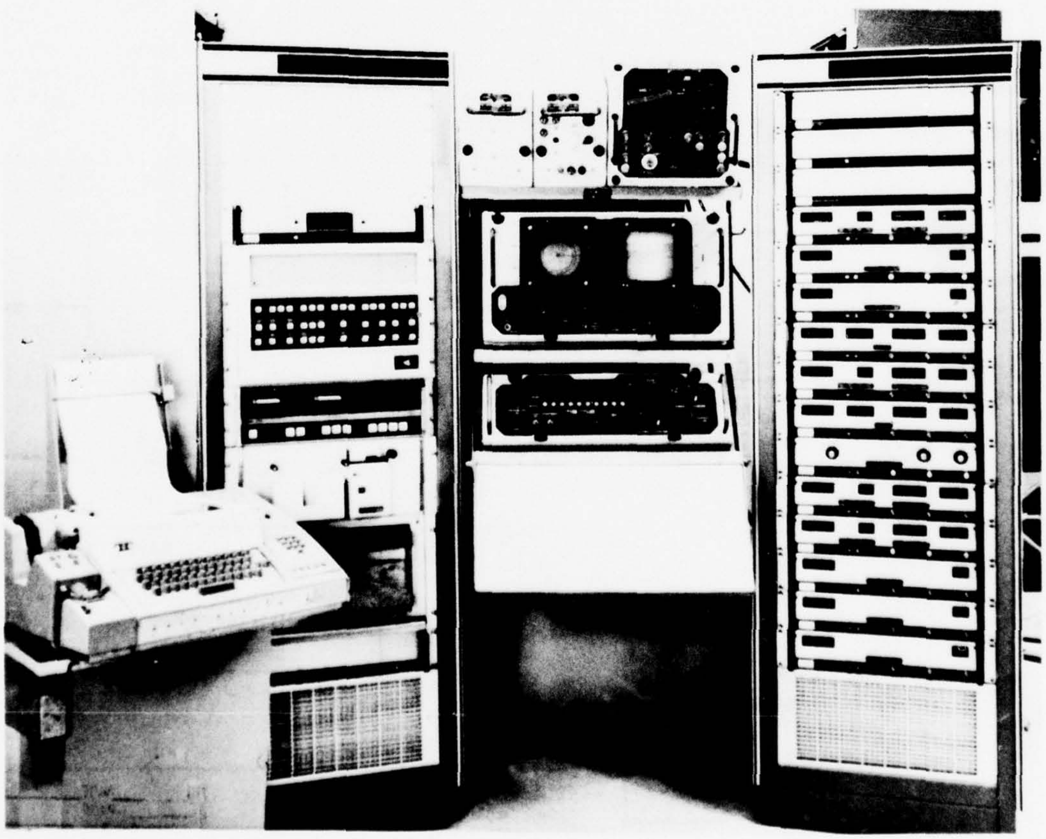

Figure 7. Part of 10A3 Simulator Facility

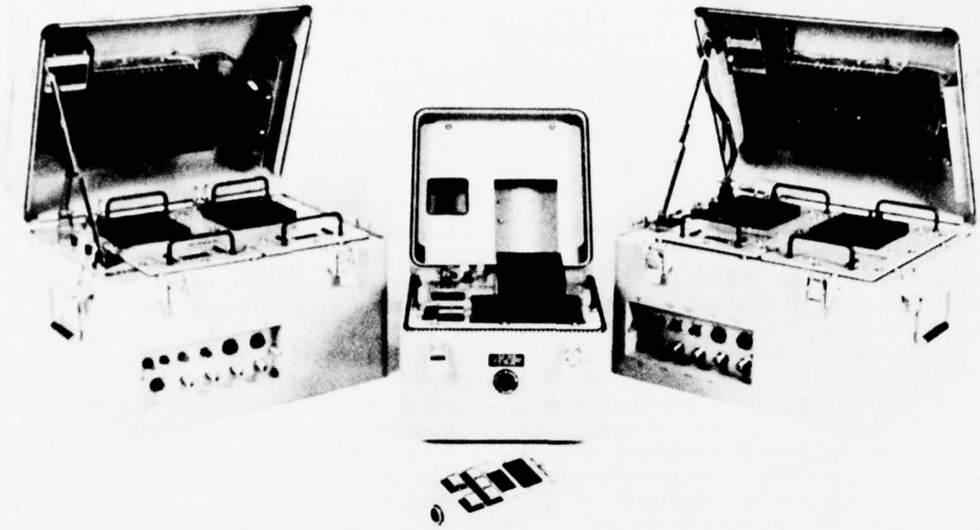

Figure 8. Typical 6000 Series Modules and Mounting Cases

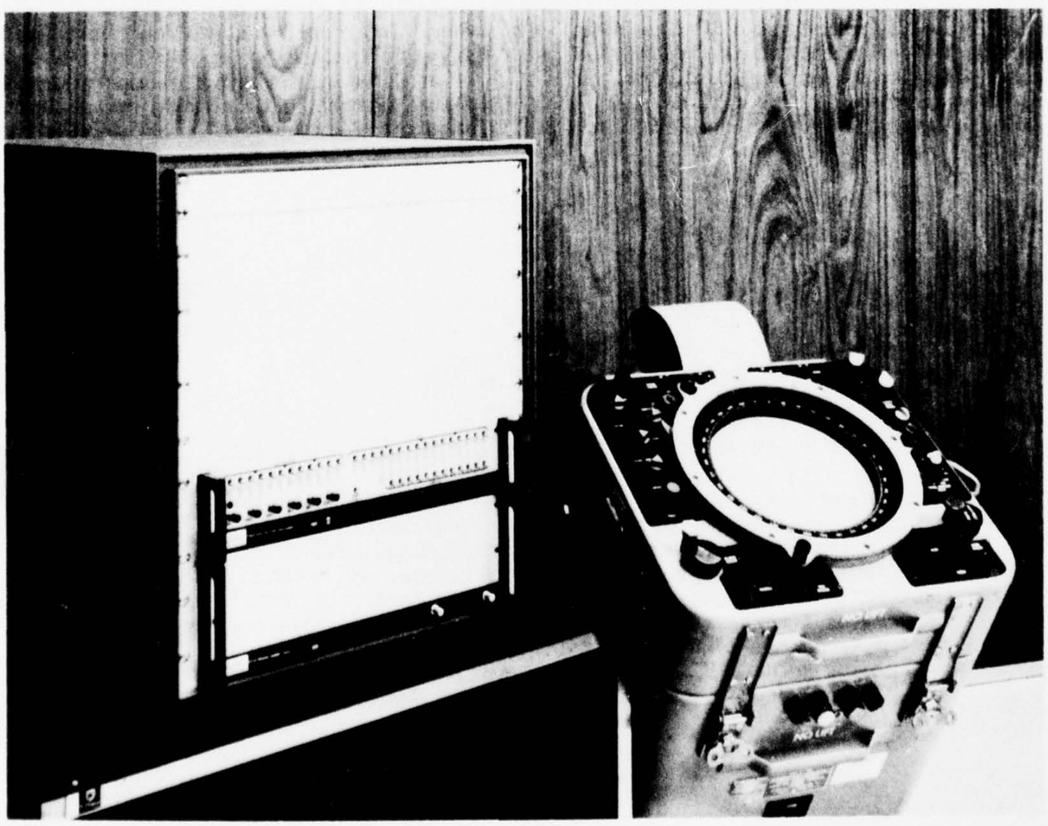

Figure 9. PPI Radar Scope Driven by Radar Target Simulator

unit through the data interface circuitry in the Pulse/Scan generator equipment. It generates all of the control signals necessary to display simulated targets on a slave PPI radar scope such as the one shown in Figure 9 (part of 10A3 Simulator). Since the placement and simulated radar cross section of these targets is coordinated with the threat signal data commands to the EW signal simulator units, the EW personnel involved in the exercise get a fully coordinated picture of the battle scenario as it unfolds.

EXPANSION OF BASIC CAPABILITY

The simulation thus far described has related only to surface ships, but it is easily extended to include submarine platforms. The only difference here is that the simulated signals must be interrupted during any time the submarine is submerged (either actually or in simulation if it is not at sea). If the submarine is actually underway during the exercise, a slight modification to the commanding scheme must be made to allow an update dump of commands to the submarine on demand. This allows the simulator in the submarine to be updated to include any parameter changes which might have been sent while it was submerged, and hence had its communication link interdicted.

EW aircraft can also be added to the problem, since flight line equipment capable of stimulating the aircraft's EW equipment and compatible with the multiple-ship simulation configuration is also available. However, at the moment, this equipment can only be used with the aircraft on the ground (or carrier deck) since it is not designed to be carried aboard the aircraft.

CONCLUSIONS

With the introduction of the Area EW defense management concept and its increasing importance in modern warfare, it is becoming ever more important to provide EW operators with realistic, cooperative, multiple-ship training in the search for, identification and location of, and proper reaction to threat signals. Further, it must be provided in the most cost effective way possible; so it can be repeated often enough to achieve not only competence but excellence of performance by EW operators.

The presented concept is a classic example of resource conservation through simulation, since the cost of installing this type of remote simulator system on a ship is less than the cost estimated by the Office of the Chief of Naval Operations for taking that same ship to sea for a single 1-week exercise. Further, this concept allows EW and radar operators to be cooperatively trained under high density, "hot war" engagement conditions, with large numbers of friendly ships maneuvering against large numbers of enemy ships which are firing anti-ship missiles, and large numbers of enemy aircraft; conditions that can (in peace-time) only be created through simulation. Therefore, this simulator based training is not only less expensive than that which could be provided by maneuvering ships against emitting signal sources, but its quality and realism are superior.

ABOUT THE AUTHOR

MR. DAVID L. ADAMY is a Systems Engineering Manager at Antekna, Incorporated. He is responsible for the design of EW target simulator systems and the conduct of simulator system study activities. For the past 15 years, he has been a systems engineer and program manager in the EW field designing (and managing programs to develop) communication receivers, radar warning and automatic jammer interface systems, and remotely controlled direction finding receiver systems. While an Army officer, he was a technical instructor at the National Security Agency. Mr. Adamy holds a B.S.E.E. degree from Arizona State University and an M.S.E.E. degree from the University of Santa Clara.

CONSERVATION OF PEOPLE, PLANES, AND

PETROLEUM THROUGH OPTIMIZED HELICOPTER

SIMULATION

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The Variable Cockpit Training System in use at the U.S. Coast Guard Aviation Training Center in Mobile, Alabama represents a drastic departure from traditional military pilot training. Through the use of a highly sophisticated flight simulator and several advanced training techinques the Coast Guard has realized dramatic savings in both training time and training costs. In addition, thousands of aircraft hours previously used in training have been released for use in other Coast Guard missions. Some of the new techniques were used in a pure aircraft training program prior to the delivery of the simulator. This allowed separate analysis of savings derived from certain facets of the program.

BACKGROUND

In 1973, the Coast Guard began using a helicopter training system incorporating a sophisticated simulation facility and many advanced training concepts never before implemented in an operational military flight training program. Three types of training are provided at the Aviation Training Center at Mobile, Alabama. Each year proficiency training is provided for all Coast Guard helicopter pilots in the HH-3F or HH-52A simulator to renew their instrument rating and provide realistic emergency procedures review never before available. This entire course, including the instrument checkride, is given in the simulator. Coast Guard pilots with rotary wing experience who are to be trained in the specific helicopter go through the Transition course. This involves training in the actual aircraft as well as the simulator. The Qualification course prepares fixed wing pilots for their rotary wing rating in the HH-52A. This also involves both aircraft and simulator training. We will discuss our first four years experience with this system, with emphasis on design features of both the simulator and the training program.

Before we discuss our new system, we will review traditional military pilot training to show the frame of reference from which the Coast Guard approached this new venture.

Traditional Subject Matter Emphasis

Prior to July 1972 all Coast Guard helicopter pilots were trained using the conventional method of training, i.e., learn aircraft systems in great detail through an instructor who stood up and lectured on the material. Flying the helicopter was not begun until the entire lecture series was completed. This was true of undergraduate pilot training with the Navy as well as transition or qualification training which was conducted by the Coast Guard.

Traditional Instructor Selection

As anyone who has attempted to do a research project in a routine pilot training program will tell you, the greatest source of variance in the way students are trained is the instructor pilot. To partially counteract this, standardized briefings are devised for each maneuver so the student will not be penalized for having an instructor who can't communicate his thoughts as well as another. In many cases instructors

are chosen not for their ability, but for their availibility. Frequently graduating students are chosen to be flight instructors. Students usually get their choice of assignments according to their class standing. Priorities are usually arranged similar to this; fighters, bombers, transports, helicopters, desk jobs, and finally (gulp) instructor pilots.

Traditional Flight Syllabus

In order to ensure adequate coverage of all pilot skills, a strict syllabus was devised which instructors were expected to follow as accurately as possible. This thorough outline of how training time was to be spent was developed partially in response to a requirement for each class to finish on a preset date. Training commands were required to turn out a given number of pilots at given intervals. In order to comply, they had to have a pretty accurate picture of such things as the rate of attrition, weather delays, and aircraft availability. From the command point of view, following a rigid syllabus reduced the variability due to individual learning rates.

It is important to note that the Coast Guard pilots who worked in developing our present training program were products of traditional military training programs. It was at times difficult for them to override their concepts of what a military training program should be like.

The first break with tradition came in choosing the officers to serve as Coast Guard instructors. When the Training Division was first established in 1965, a decision was made to select instructors from operational pilots who first, wanted to be instructors, and second, were known to have the basic skills and personality to be good instructors. By the time this new training system was conceived there was on hand a group of highly motivated, highly respected instructors.

Still, there was a reluctance on the part of the instructors to develop such a radically different program as was envisioned. Their arguments can be summarized in two categories: First, they noted the present system had been successful for years and saw no reason to change; and second, in most cases those who had experience with simulators felt it had been a bad experience with no real training value.

DEVELOPMENT

In 1969, the Commandant requested a study of Coast Guard aviator training requirements to determine whether training costs could be reduced by using advanced training technology. This study, conducted by HumRRO, included a task analysis of operational pilots in each Coast Guard airplane. (Hall et al., 1969) It was determined that a revised training program taking advantage of new concepts and technology could reduce training costs considerably and increase overall training effectiveness. (Caro et al., 1969) The decision was made to develop a Variable Cockpit Training System (VCTS) for both Coast Guard helicopters.

From its inception in 1969, the VCTS was thought of as a flight training system which had a sophisticated simulator as an integral part, rather than as a simulator which might be squeezed into an existing training program. Design features of the simulator were evaluated on the basis of training value per dollar. As a result, we have no visual system which may have saved no more than two hours per student given the state of the art at that time. Six degrees of motion, on the other hand, were considered indispensable because of the cues provided for many of the malfunctions.

Primary contracts were eventually let to Reflectone, Inc. to build the simulator itself, and to HumRRO for assistance in developing the training program. An additional subcontract was let to NAVTRAEQUIPCEN for technical expertise in developing the specs for the simulator.

Training Program Features

Flight instructors were actively involved in developing the training program they were eventually going to use. Three instructors from each aircraft were given primary responsibility for creating the new training program with guidelines and assistance from HumRRO personnel. From time to time, other instructors were consulted regarding their area of expertise. Each of the three

instructors was assigned to the Reflectone factory to assist in testing and acceptance of the new simulator for about a month at a time. The other two worked on writing the course material. This rotation was devised to provide them with a total picture for the new program. This also reduced the problem of the acceptance pilot adjusting to the simulator.

Several new training concepts served as focal points for the development of the new training system. As might be imagined, many heated discussions took place before implementation of such a radical departure from traditional flight training. In discussing each of these concepts, we will summarize some of the problems envisioned by the instructors and then report on their subsequent experience.

How to Operate the System

It was determined that the training program should focus on training objectives that can be evaluated by observing student behavior. These objectives should be related to tasks that a pilot might be expected to do in the operational environment. The student should know how to operate the aircraft systems in all normal and emergency conditions. He would not need to know all components of each system. If he can't control it from the cockpit, he doesn't need to know about it. The old school flight instructors were a little less than enthusiastic about this idea. Many examples were cited where a pilot had saved his "bacon" by knowing how to jury-rig an immediate correction for a system problem based on his thorough knowledge of the system. This is the most valid argument against the systems approach to training, and it must be dealt with. The answer, of course, is to ensure that all conceivable ways to operate a system from the cockpit are covered for all conceivable malfunctions.

In retrospect, this concept has been a great time saver in all courses. Training objectives defined in this way have proved successful as reflected in follow-up critiques from the operational units.

Proficiency Based Advancement

As soon as a student could perform a particular operation at an acceptable level he should be allowed to move on to the next level of difficulty. This is imperative when setting objectives in terms of expected behavior rather than material to be covered. When the objective has been met the lesson is complete.

It has been documented that acceptable performance to one instructor may not be acceptable to another. (Koonce 1972, and others) Pinning down the acceptable performance criteria for each maneuver required a lot of discussion. These ranged from very detailed to very brief. The general consensus of the instructors was that recording great amounts of detail was neither required nor desired during the flight. A form was finally adopted which dealt in broad maneuver categories requiring only a mark to show whether the attempt was "Satisfactory" or merely a "practice" trial. Additional detail could be added after the flight in space provided. The guidelines for satisfactory performance are still primarily subjective, however, they are validated as instructors rotate students during the latter phases of training.

Training Managers

Instructors were given the role of managing the conduct of each course they taught. One instructor was to take his students through the entire training program modifying it as necessary to ensure that his students met the end of course objectives. He would be responsible for all phases of training from study assignments and systems information, to the cockpit procedures training, the simulator, and into the aircraft. The academic phase was integrated into the simulator and flight phases. In the later operational phases the students would fly with other instructors to validate initial training and provide feedback to the principle instructors.

There was a general uneasiness among the new "training managers"

who felt the need for the more comfortable guidelines they had had with the strict syllabus approach. They were eventually made comfortable with a list of maneuvers which must be accomplished satisfactorily before moving on to the next phase. Material previously presented in the first six lessons was collasped into "Phase One, Basic Land" with no time divisions or suggestions for how to use the lesson time.

Because the concept of Instructor Manager was new, it was difficult to provide the instructors with detailed descriptions of what steps to follow in setting up an outline of instruction. At first, great care had to be taken that each instructor did not set up his own mini syllabus, but rather used a proficiency based method of instruction.

As instructor managers gained experience they became more flexible in taking advantage of their freedom. New instructors who have come aboard after the first year are more receptive to this idea. Many of them went through this training system in their initial transition, and again when they went through the instructor course. As evidence that instructors are using their own judgement as to the time required in each phase, the standard deviation on total aircraft time in the HH-52A Transition Course has increased from 2.9 hours prior to VCTS to 7.2 hours in 1976.

New Training Program used without Simulator

As work on the training program and material progressed ahead of the hardware delivery, it was possible to experiment with some of these concepts in the all-aircraft HH-52A qualification course. Table 1 shows a comparison of times in the Qualification course, prior to implementation of the systems approach, with times using the new procedures, but without the simulator. Clearly, some of the savings attributed to the new training program are achievable without the simulator. No degradation of student terminal performance was noted by the admittedly skeptical check pilots, or subsequently by the units to which they were assigned.

TABLE 1. SAVINGS IN FLIGHT TIME USING ADVANCED TRAINING CONCEPTS WITHOUT THE SIMULATOR.

HH-52A QUALIFICATION COURSE

	Mean Aircraft Time	SD
OLD SYSTEM	77.3	3.8
NEW SYSTEM	67.7	3.6
SAVINGS	9.6	

SIMULATOR FEATURES

The VCTS simulator complex consists of two highly sophisticated flight simulators - one each for the HH-52A and the HH-3F helicopter now in service. The simulators were built by Reflectone, Incoporated using a single Datacraft 6024/3 computer with a high-speed disk operating system. Each cockpit is installed on a six post synergistic motion system providing six degrees of freedom. Training time lost to maintenance problems remains below one percent.

Advanced training capabilities include performance playback, automated demonstrations of selected maneuvers, automated performance scoring and in-cockpit control of all training and environmental conditions. The instructor rides behind the students in position to both monitor their performance and operate the simulator controls. Two students receive training as a flight crew, with one acting as copilot. They must react to various malfunctions as a team without reliance on a safety pilot.

We will discuss each of these features as to their actual usefulness.

Performance Playback

The performance playback feature was intended to be used in debriefing students after a maneuver or malfunction. Although the capability exists to playback from one to five minutes, rarely is anymore than one minute used. Instructors find it very useful especially in high workload or stressful situations to play back the last minute of the event. We would like to have

the capability to replay less than a minute as most such cases are of very short duration.

Automated Demonstration

Manuevers can be stored as performed by experts for demonstration. We have recorded many of the flight training maneuvers, but find little use for this feature. It would be of more value in primary training than at the advanced level undertaken here. Instructors feel that training is more effective if the student attempts the maneuver himself. Students at this level have little trouble visualizing a new maneuver from a verbal description.

Automated Performance Scoring

Subroutines within the simulator program allow for recording of frequency and time out of tolerance for each of twelve aircraft parameters when either the "exercise" or "checkride" mode is selected. The checkride module allows data to be stored permanently for statistical comparison. This data bank is now large enough to react to major changes in the training system.

We have previously reported mild correlations between instructors subjective grades and the computer scores (Povenmire and Ballantyne, 1976) and a highly significant differentiation between computer scores of students and those of instructors on the same checkride (Povenmire, 1974). It is obvious to us at this point that automated scoring may provide useful data regarding one phase of pilot performance - namely, accuracy of tracking. However, it is impossible to automatically measure all factors that indicate pilot performance. Many judgemental and rational processes are much more important than how well he maneuvers the aircraft.

Instructor in the Cockpit

We have realized all of the anticipated benefits and none of the anticipated disadvantages of having the instructor ride along in the moving cockpit. It was predicted that he might have serious orientation problems due to the washout features of the motion system which presents only onset cues and then returns to a near level attitude regardless of the simulated attitude. However, because of their high level of flight experience, instructors automatically look to the cockpit instruments and justify themselves to simulated pitch and bank information rather than look out the back window to find real attitude.

With all simulator controls at the instructor's console there is no need to have an additional operator at a remote site, thereby reducing the manpower requirement. When both simulators are operating there are two students and one instructor in each cockpit. There is also a technician on call in case of a system malfunction, but he is free to do other projects.

The perfect instructor, according to conversation with one well-known aviation psychologist would be both mute and quadruplegic. (Hagin 1972) We come close to achieving his desired conceptual result with healthy instructors. The instructor does not interact with the students in the context of the flight. If students tend to rely on him he overtly discourages them. If asked for advice he says something like, "I don't know sir I'm just a crewman." He is out of the line of vision for the students so they are forced to interact as a crew and troubleshoot between themselves. The instructor will intervene and freeze the simulator when the students either use an inefficient strategy in troubleshooting or become disoriented in an instrument maneuver. He then discusses the operation while the cockpit is frozen, or plays back their performance to show where they went wrong. His physical presence in the cockpit is very unobtrusive, but very essential in his role as a performance evaluator and prescriber.

ONGOING DEVELOPMENT

After three years of operation with the "new" training system shifts of personnel in leadership positions resulted in a questioning analysis of the program as it existed. Subsequently, two major areas were identified for critical analysis:

1. What is the training program accomplishing?

2. Is the training program responsive to the needs of operational Coast Guard units?

Program Evaluation

For the first three years training program accomplishment was measured in three separate ways - 1) Student critiques; 2) critiques completed by graduates' Commanding Officers and 3) automated performance scoring on an instrument checkride in the simulator. The two critiques were subjective in nature while the latter gave us detailed data on time in seconds and frequency that the pilot exceeded preset flight parameter limits. The numerical data clearly demonstrated that the performance of Coast Guard pilots on the instrument checkrides was improving year by year. (Povenmire and Ballantyne, 1976)

However, since the checkrides were administered only at the end of a course it was unclear as to whether the improvement was in the pilot or in the training programs. The very real possibility of an undesirable tendency for the instructors to teach the checkride existed. The data gathered did not provide any confirmable information on the pilot proficiency levels or tendencies in the service. It could be assumed that the lowering of checkride scores showed an increase in servicewide pilot proficiency, but other explanations were also viable. The student and Commanding Officer follow-up written critiques continued to indicate basic satisfaction with the level of training received. It was apparent that we were doing a reasonably good job of training while we had the pilot captive in Mobile but we weren't satisfied that we were able to evaluate the overall pilot training program of the Coast Guard. Accordingly, 1 January 1976 the Proficiency Course was revised so that the scored instrument checkride was administered as the first event.

This slight change designed specifically to provide a measure of Coast Guard wide proficiency levels also provided several synergistic effects. The instructor was able to identify individual pilot weaknesses while simultaneously completing the check flight requirements for annual instrument rating renewal and adding to our numerical score data base. The multiple goal accomplishment at the start of the course also freed two scheduled training periods for additional emergency procedures training as well as permitting the students time to practice maneuvers that they personally wished to work on. The numerical data accumulated to date indicates that the overall level of pilot proficiency has in fact improved over the years the simulator has been in use (Povenmire and Ballantyne, 1976), and each training program was raising skill levels during the course of the pilot's stay in Mobile. Allowing the pilots time to practice the procedures they wish has restored their interest in the course and eliminated the anticipated boredom.

While we were convinced that we were improving the overall skill levels of our helicopter pilots, the major goal of any training program is providing an end product that the user desires. Analysis of Transition and Qualification student critiques and surveys of air station Commanding Officers indicated that graduates of our Transition and Qualification courses were not performing typical copilot duties as well as desired. Subsequent review of our training program revealed that although the students receive many hours in the simulator as copilots, the real world of communications and search planning are not well simulated.

Program Changes

A slight shift of training emphasis in the simulator and addition of a practice search mission in the aircraft provided a quantum increase in the level of the graduates copilot skills with no increase in the overall course length. The shift also permitted the elimination of a two week navigation review course that Coast Guard helicopter pilots were attending at NAS Pensacola as part of their undergraduate pilot training. The success of a slight change in course content in meeting operational requirements illustrates the need for constant review of training program goals.

We also formalized a program to monitor reports of aircraft equipment failures submitted from the

field units. As new problems would arise we would add them to our list of simulated malfunctions. This continuous updating of the training to reflect operating experience has added greatly to student pilot enthusiasm and acceptance. Our experience has definitely shown that advanced flight simulators will be most effective if the end product of the training program is what the user desires. Effort expended to keep simulator training current and relevant throughout the life of the training program is as important as effort spent in the original design of the simulator.

As a result of the new policy providing no proficiency flying for pilots assigned to non-flying billets, such as those at Coast Guard Headquarters, a new course was developed to requalify these people when they return to operational flying. This course has no previous counterpart and has not been included in the analysis below.

SAVINGS IN TIME

As we have shown above, some savings attributed to advanced training concepts used without the simulator were demonstrated in the HH-52A Qualification Course. Additional savings in excess of 30 hours per student were realized in this course when the entire training system was implemented.

In the HH-52A Transition Course additional training requirements were identified which required additional training time. Unfortunately, we cannot identify the exact amount of time required for each student to meet these additional objectives; a conservative guess based on estimated flight time required to teach each new skill as part of another flight rather than as a separate flight solely for that purpose might easily account for between five and seven hours. On the other hand, after training students to react properly to an engine failure in the simulator we had to add a maneuver to the simulator training program called "practice autorotations." This was to preclude a student from shutting down the engine in a practice situation in the aircraft and to assure that the engine was brought back on the line prior to the critical point. Although the total cockpit training time increased over the old Transition Course, we have reduced the calendar time requirement from six weeks in the previous course to four weeks. The HH-3F Transition Course has actually produced an average savings in excess of seven hours over the old course.

Table 2 summarizes these savings for the three courses where aircraft are still used. In addition to these savings, one HH-52A aircraft was removed from the Aviation Training Center allotment when the VCTS was implemented.

TABLE 2. TIME SAVINGS PER STUDENT FOR EACH COURSE

	HH52A QUALIFICATION COURSE			HH52A TRANSITION COURSE			HH3F TRANSITION COURSE		
	FLIGHT	VCTS	WEEKS	FLIGHT	VCTS	WEEKS	FLIGHT	VCTS	WEEKS
OLD METHOD	77.3		9	*35.8		6	34.9		6
NEW METHOD NO SIM.	67.8		7						
COMPLETE NEW SYSTEM	36.6	23.9	5	30.8	16.4	4	27.3	30.8	6
TIME SAVED	40.7		4	5.0		2	7.6		0
STUDENTS PER YEAR	18			30			32		
TOTAL ANNUAL SAVINGS	732.6			150.0			243.2		

*Adjusted time reflects approximately five hours of additional training which was not included in previous course but is presently being given.

Additional savings were realized with the implementation of the Proficiency Course. This was an entirely new course intended to centralize and intensify the instrument and emergency procedures training that was previously being done at each unit. No hard figures are available to indicate how much training was actually replaced. As a matter of policy the annual training requirements for each aviator was reduced by 12 hours. This releases approximately 6,000 hours a year to the Coast Guard for use in other missions.

SAVINGS IN DOLLARS

In determining the cost per hour for running the simulator, all costs associated with the VCTS were itemized and divided by the actual number of training hours utilized. Costs included the following: field service maintenance, student travel for all courses, student per diem allowance, salaries of five civilians and one officer added when VCTS became operational, and, last and least, utilities. These costs have increased over the past three years along with everything else. However, utilization has increased proportionately. Our costs per student hour have remained between 48 and 60 dollars.

The total cost for the first four quarters of fiscal 1976 was $404,744. During the same period 7,845.8 student hours of training were conducted yielding a cost per student hour of $51.59.

Using operating costs established for federal budget determination, actual aircraft hours saved in the Qualification and Transition courses, and the aircraft hours released from the training requirements by the Proficiency to other Coast Guard missions we have been able to demonstrate savings in excess of $2 million during 1976.

SAVING OF LIVES

On several occasions our simulators have been used to assist in accident investigation. The accident review board brought both pilots to Mobile after an HH-3F had become uncontrollable. By simulating the intermittent failure of the suspected components the pilots "confirmed that the simulator maneuvers were identical to the aircraft reactions the night of the accident." (Tydings, 1977) Although this malfunction had been simulated in the Proficiency Course, it had not been shown in the intermittant mode. This has since been added to our list of required malfunctions in the Proficiency Course.

On another occasion, an accident review board attributed an HH-52A pilot's successful autorotation in an extremely critical realm of flight to "low altitude techniques demonstrated and practiced during the annual training received in the Variable Cockpit Training Simulator (VCTS) at Mobile." (USCG, 1977).

Although documented only by a phone call, we have saved at least one aircraft. The pilot of an HH-3F called the Chief of the Training Division to express his gratitude after having virtually the same serious control malfunction which had caused the crash of the HH-3F discussed above. He said, in effect, that because he had seen it in the simulator he was able to recognize it immediately and switch to a redundant system. He continued to his destination through the clouds over the mountains near Kodiak, Alaska. Acquisition cost for one HH-3F is just slightly higher than the cost of the entire VCTS simulator complex.

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AN APPROACH FOR IMPROVING FLEET TRAINING THROUGH TELECOMMUNICATIONS SUPPORTED SIMULATION

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SUMMARY

Maintaining fleet readiness in light of today's resource constraints and approaches to operational training is extremely difficult. Time spent at sea is minimal, individual ship training is not well structured or integrated and joint ship training exercises are few relative to need. Continuation of this condition may not be necessary, if the U.S. Navy takes advantage of telecommunication and computer technologies. With these technologies and a common centralized data base most U.S. ship crews located in port could train as if at sea. Individuals could be trained to operate their respective equipment; train as a team; and train as a weapon system.* Further, ships in port throughout the U.S. could be aggregated as a task force and trained as if in a fleet exercise. In addition, ships at sea or a combination of ships at sea or in port could be pooled to train together. Such a system has the potential for saving millions in operating, maintenance and munitions costs, but still produce a fleet trained and ready to neutralize any attack by an adversary.

INTRODUCTION

A constant requirement that must be met by the U.S. Navy is maintaining a high-level of operational readiness so that all possible eventuality can be properly addressed. Meeting this requirement has always been difficult, but today the problem is compounded by limited resources, the constant introduction of new equipment and ships, and the rapid modernization and challenge of the Soviet Navy.

Looking at the essence of operational readiness, the backbone has been the training provided on and by the individual ships. Each is expected to follow basic training guidelines, but operationalize as they see fit. Each individual is expected to reach a level of proficiency relative to assigned tasks and to operate as a member of a team. Each team is trained to function as an efficient and effective entity interfacing with other teams, aggregating to the total weapon system -- the ship. Unfortunately, this training autonomy concept does not always produce the desired results; consequently, there is a spectrum of readiness within a ship and among the ships in the fleet.

The other key component of operational readiness is the fleet exercise. While each ship is responsible for its own operational readiness, they must eventually come together to function as a member of a team. Fleet exercises are the basic means used to train and test the capability of the ships to perform their individual and team roles in varying conflict scenarios. While fleet exercise training is desirable because it is as close to reality that is possible, few are being conducted due to fuel constraints and the operational and maintenance costs.

Because of the above problems, the operational readiness of the U.S. fleet may not be what it should be. However, it may be possible to rectify this situation and save a considerable amount of money over the long run, if the U.S. Navy takes advantage of existing technologies to improve operational training.

THE TECHNOLOGIES

Two basic technologies which may permit the U.S. Navy to improve their operational readiness posture are telecommunications and computer technologies. Advances in the computer field over the past two decades are now being capitalized on to provide computer support to meet almost any need. Similarly, advances in telecommunications now permit reliable communication links to nearly any location on the earth. By combining these technologies it becomes possible to develop a large network of interrelated data communications and data processing devices. Consequently, integrating computers with today's telecommunication can provide a flexible, accurate, and high-speed transmission along with a central location for the accumulation, processing and the evaluation of data.

These technologies are not foreign to the U.S. Navy. They are in daily use. Literally hundreds of computers are in use in the U.S. Navy to include "minis" on board ships and "macros" in various CONUS command centers. Every conceivable telecommunications means is used to include communications satellites, to transmit data and information. Therefore, the technologies that might contribute to the improvement of operational readiness training already are in use. What

*"Weapon system" refers to a ship, submarine or aircraft and is synonymous with "unit."

is needed is a reorientation of thinking towards using them for operational readiness training.

THE OPERATIONAL READINESS TRAINING (ORT) CONCEPT

Basically, the heart of the ORT system would be a centrally located computer which would be programmed to simulate a range of problems that would be induced into the instrumentation of weapon systems to include surface and subsurface vessels and airborne vehicles. The system would be flexible enough to stimulate a single piece of equipment on one or multiple weapon systems. Further, it would be able to aggregate equipment stimulation to effect specialized team training. Moreover, it also would be able to address task force type training, stimulating multiple pieces of equipment in a large number of weapon systems according to a range of scenarios. With the aggregating feature individual equipment operators, combat teams, a ship or a task force would be able to be trained and evaluated.

Another feature of the system would permit ships that are in port, or a combination of port and sea vessels to work as if they were at sea in fleet exercises. The system would have sufficient coverage to include CONUS, the Atlantic and Pacific Oceans and the Mediterranean Sea. Consequently, ships in port throughout the U.S. could participate in ORT, as could ships at sea or in port throughout the world. The ORT system would be able to tie the ships together in any combination from any place in the world and treat them as if they were working together at one geographic location. Figure 1 delineates how weapon systems in the CONUS vicinity might be brought together under the ORT system.

ORT SYSTEM COMPONENTS

The ORT system would have three basic components:

1. Shore Training Control Center

2. Communications System(s)

3. Unit Training Mode Control and Interface System

Shore Training Control Center

The Training Control Center would provide for the initiation, control and evaluation of selected training exercises. It would require a large facility; a staff of training experts and support personnel; and the hardware and software needed to provide operational scenarios to units for training purposes. The training facility concept would be very similar to existing facilities such as the Fleet Combat Direction Systems Training Center, except the problems would be much broader in scope. For example, a single facility may incorporate the features of many existing training systems [i.e., Device 2F87, Weapons Systems Trainer; Device 14A2, Surface Ship ASW Early Attack Weapons System Trainer; Tactical Advanced Combat Direction and Electronic Warfare System (TACDEW) etc.]. In addition, new features may be provided for engineering drills, navigation exercises, etc.

While the discussion thus far has eluded to a broad range of training that could be provided to the fleet, the major emphasis in the remainder of the paper will be placed on training in ASW/AAW. Accordingly, the Training Control Center would provide simulated training problems similar to those currently operational at the various facilities.* The difference lies in the degree of sophistication in simulating the "real world" and the "place of training." As with other training exercises, in ASW the general problem parameters such as ocean environment; target class, its course, speed, depth, etc.; and similar data for friendly vehicles (LAMPS, S-3As, submarines and surface vessels) would be initiated and controlled at the Center. However, the signal inputs for Sonar, Radar, ECM, etc. would be simulated on each unit.

The advantage of this concept over the current system is that, while the training would be controlled from shore the actual training would be conducted at the unit level. This would allow several units to participate in coordinated training exercises, whether in port or at sea. Also, each unit's performance can be evaluated by experts located at the Center as well as by personnel on the ship. The primary purpose of the Training Control Center would be to provide the fleet with operational training scenarios and evaluate their readiness.

*The range of training provided could include Naval War Gaming provided at the Naval War College in Newport, Rhode Island, LAMPS and S-3A pilot training (i.e., Device 2F92, S-3A Weapons System Trainer) sonar classification and operator training (i.e., Device 14E19, Basic Operator/Team Trainer, AN/SQS26 CX Sonar) and anti-air warfare training such as provided by the Tactical Advanced Combat Direction and Electronic Warfare System (TACDEW) at Dam Neck, Virginia and San Diego, California.

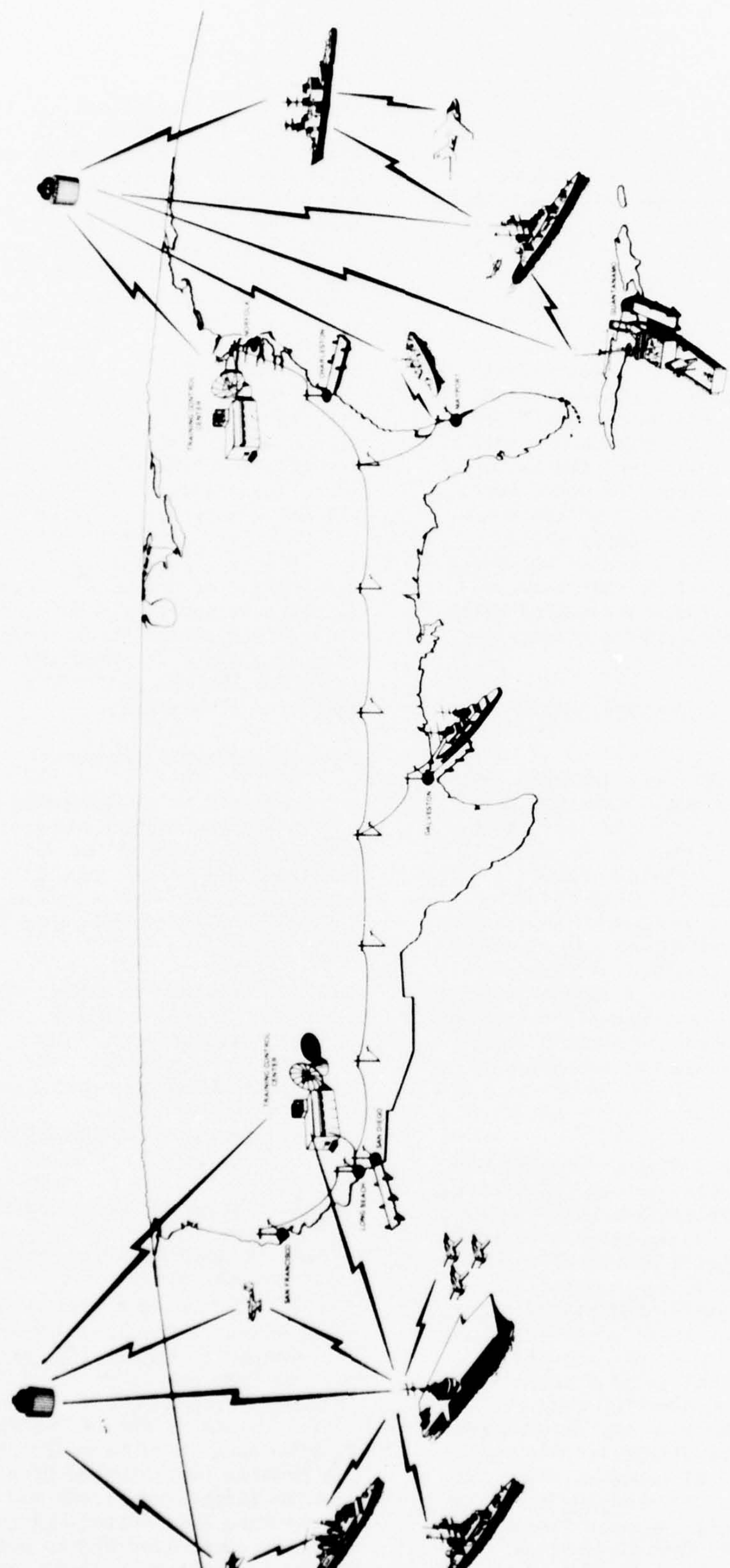

Figure 1. Fleet Training Operational Schenario

Communications System

A variety of communication modes could be used to deliver and receive problem data from Navy units. For example, the Naval Tactical Data System (NTDS) Link 11 and 14 features should be considered in the design of the communications system especially for surface warfare training. For units that are on shore or temporarily in port, a direct line link may serve as the most efficient channel for Training Control Center to unit communication. This might include the AAW Mobile Training Van or MISTER concept.* A variety of communications approaches should be studied, such as AUTODIN and FleetSatComm. The actual communication network would most likely consist of a combination of systems with the determining factors being their availability; the need for a real-time system capability; the types, volume and rates of data transfer; and the costs associated with the operation and/or design of a completely new communications system.

Unit Training Mode Interface and Control System (UTMICS)

The UTMICS would be the final component of the fleet training system. The UTMICS would be physically installed on board each appropriate unit to: 1) provide an alternate mode of operation (training mode); 2) control, process and distribute problem data received from shore thus furnishing simulated inputs to tactical subsystems and components on board the unit; and 3) receive and transmit key feedback data to the Training Control Center for the purposes of critiquing and evaluating the training problem. Units receiving the UTMICS would be provided with a complete training mode capability without sacrificing the tactical mission of the unit or safety of the crew. For example, on a destroyer the training mode would provide a capability of switching radar, sonar, intercommunication switchboards, propulsion systems, etc., either jointly or independently to the training mode. This would allow the injection of simulated control and signal data for conducting individual and/or team training. Specific functions which could be simulated include the own ships' course and speed; radar, ECM and sonar contracts; and the firing and tracking of delivered weapons. The degree of simulation and the physical design of the UTMICS would depend on the type of unit, the fidelity desired, and several other factors which must be further analyzed but not within the scope of this paper.

Figure 2 presents a general functional description of a UTMICS. Again, the primary function of the system is to provide a decentralized equipment and subsystem simulation capability on board the operating unit but under the control of a training problem delivered from shore.

A Standard UTMICS System

It would be advantageous to build a standardized UTMICS configuration that could be tailored to the unique interface requirements of each type of unit. With a microprocessor, such a system can be built. The basic elements are shown in Figure 3, which are:

1. External Interface Processor
2. Main Computer
3. Problem Data Storage Unit
4. Demand Driven Multiple Access Bus
5. Equipment Interface Ports
6. Signal/Data Converters

The problem data from shore would be received, controlled and transferred to the Demand Driven Multiple Access Bus (DDMAB) via the External Interface Processor(s). One or several processors could be used depending on the volume of data to be transferred. Problem data would be read into and stored at the Problem Data Storage Unit. The data would then be further processed and routed to the appropriate destination via the DDMAB which would be controlled by the main computer. The equipment input ports, consisting of one

*This concept deals with providing shipboard training and system testing capabilities by physically interconnecting a shore based simulator (Mobile Van) to systems on board the unit. Recent projects sponsored by the Navy in this area include the Digital Accoustic Sensor Simulator (DASS) and MISTER. The Naval Surface Weapons Center is investigating DASS as a test bed for ASW/AAW aircraft training. The MISTER was to be a surface shipboard combat system pierside trainer. However, apparently the Navy has decided to discontinue the project primarily from cost rather than technological problems. In another effort the Navy is studying the feasibility of a Surface Operator Tactical Training System (SOTTS) for a prototype system to support the FFG-7 Class Frigate.

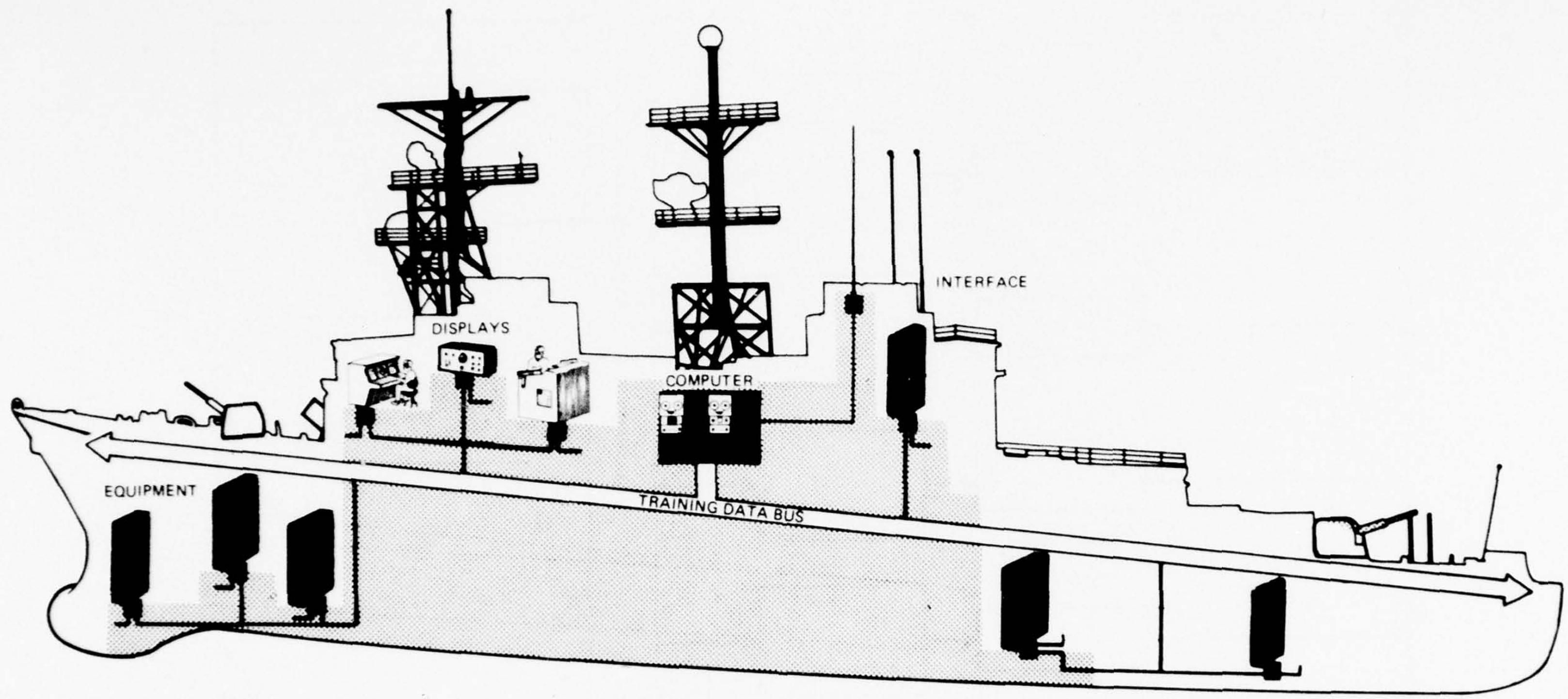

Figure 2. Functional Overview of Shipboard UTMICS

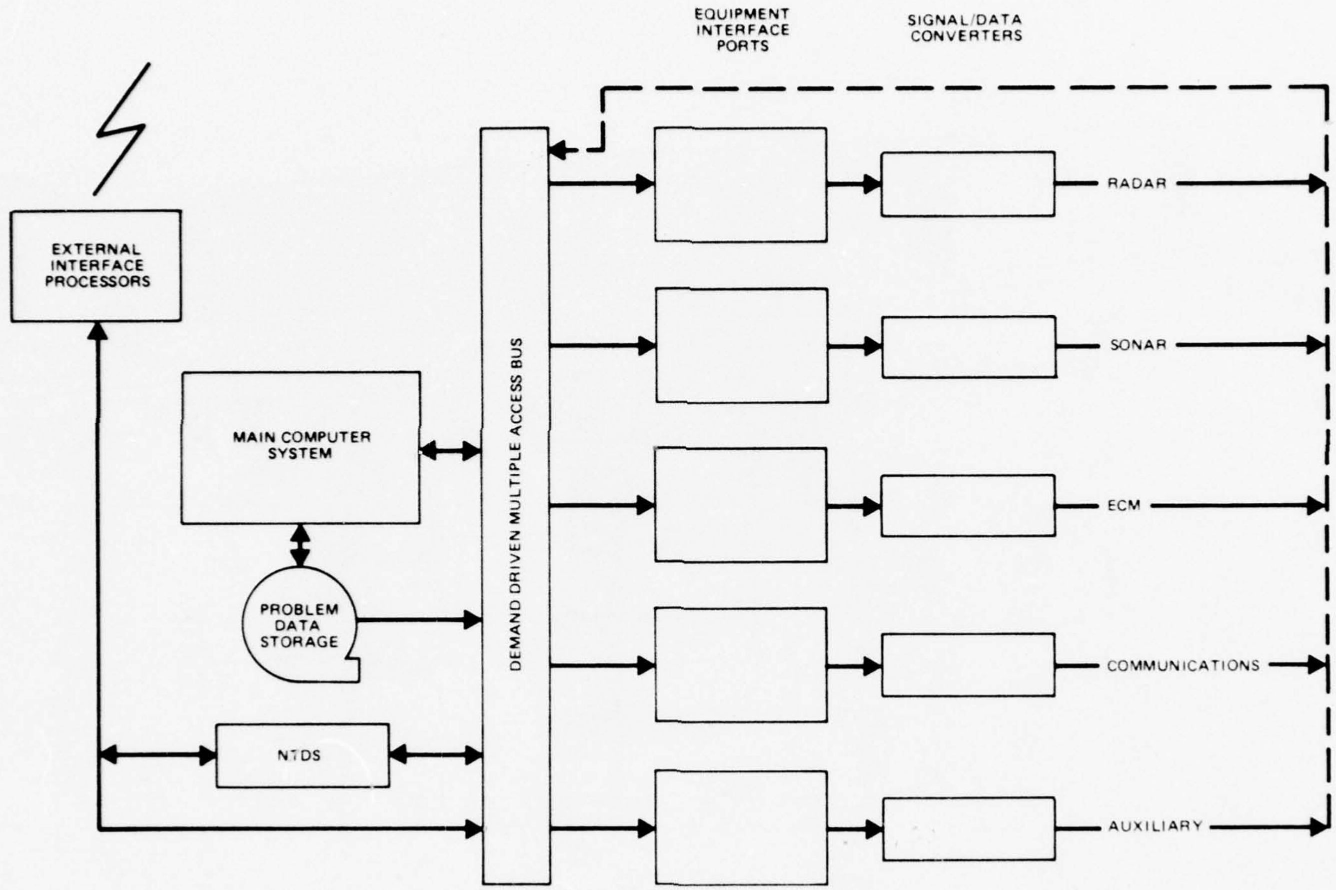

Figure 3. Standard UTMICS Configuration

or several microprocessors, would convert the parameter data to front end system signal data. Then depending upon the nature of the data, it would be formatted and injected into the system via a multiplexer or signal generator. This basic system could be expanded simply by adding ports (microprocessors) and interface equipment/software. Feedback data would be routed back to the control center using the same system by simply monitoring system control settings and unit communication circuits.

APPROACHES FOR PURSUING AN ORT SYSTEM

There are several approaches which might be followed to study, design, develop and implement a fleet training system concept. One approach would be to look at a specific requirement for fleet training and not attempt to solve the problems of the entire fleet at one time. For instance, the Navy could study, design and demonstrate a fleet training capability for ASW on board a specific class of destroyers. If this proved successful, the concept could be expanded to include AAW, engineering and navigation training. A second approach could be to investigate the requirements for a specific type of training but which may include several types of Naval units (i.e., air and surface ASW fleet training). Then based on the requirements and existing fleet training capabilities, a training system concept would be designed and tested on board selected (pilot) units.

The above approaches would apply to both current and future fleet training requirements. However, a third approach would be to investigate the training requirements for only future operating units. The concepts would be designed and tested to the extent practicable on existing vessels. Then, future procurement efforts would have detailed specifications built into the system design requirements of all applicable Naval vessels.

Regardless of the approach followed, it must be consistent with the Navy's objectives for providing improved training through simulation at an affordable cost. In addition, the concept must be totally supported by the fleet.

CONCLUSION

Because of the limitation on resources and time at sea, there is a need to explore cost effective approaches for improving operational readiness training. The ORT system is only one of several alternatives that can be pursued; however, it has considerable merit since it could establish a centralized frame-of-reference to train and evaluate individual crew members, the combat team and the ship as a whole in the performance of its mission. Further, ships on all coasts can remain in port and still train as if at sea. Finally, the system can be implemented using a number of approaches. Nevertheless, a more detailed analysis of the concept is needed before a true appraisal of the merit can be determined.

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TECHNIQUES OF QUANTITATIVE PERFORMANCE MEASUREMENT FOR ASW TEAM TRAINERS

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INTRODUCTION

The Need for Quantitative Performance Measurement

Rapidly escalating costs in operating weapon systems, coupled with energy shortages, has drastically affected at-sea combat team readiness training. Simulator/trainers are increasingly depended upon as the only economically effective alternative to provide this training. The increasing dependence on simulators, along with the availability of advanced computer technology, has led to higher demands for proof of training effectiveness. Team trainers, in particular, due to problem complexity, need validation of effectiveness. This need for proven effectiveness has placed an unparalled demand on the instructor's ability to objectively and comprehensively evaluate individual subteam and team performance.

Evaluation of complex interrelated and interdependent performances in team exercises is extremely difficult at best. This difficulty has resulted in elevated interest in the application of CAI/CMI. But the use of CAI techniques requires the capability to effectively evaluate the current performance level of trainees as well. (Goldstein, 1974). This evaluation is necessary so that appropriate courseware logic can be brought to bear as the driving function in the control of exercise content, complexity, and difficulty. Therefore, the development of objective performance measurement techniques is a prerequisite to the use of CAI as well as for proof of training effectiveness.

Honeywell is currently involved in a study of techniques and concepts that will provide detailed team, subteam, and individual performance measures for training evaluation. The purpose of this paper is to describe the requirements for ASW performance measurement and a preliminary concept of a model which meets these requirements.

Background - State of the Art in Performance Measurement

It was noted at the 9th NTEC Industry Conference, 1976 that: "After more than 30 years, the rating scale remains the basic evaluation method for instructors" (Shipley, Hagin, and Gerlach, 1976).

It was further noted, with respect to ASW trainers specifically, that ASW exercise evaluation relies primarily on subjective instructor scoring of loosely defined areas of performance. Figure 1 illustrates this scoring method and points up the conclusion that ... "A valid scoring system requires the use of objective methods ..." (Copperman and Asa-Dorian, 1976). This example draws attention to the fact that current evaluation: (a) is heavily dependent on subjective opinion, (b) places heavy emphasis on communications evaluation, and (c) is not efficient in identifying specific areas of needed improvement, with examples of poor performance. Clearly, the need for valid and reliable quantitative performance measurement paradigms is mandated by the need for proof of effectiveness and applications of CAI.

A previous unpublished study found that as many as 60 to 70 measures of performance were available and could be used for ASW training. However, the usefulness of measures simply because data are available to obtain them, is questionable. Vruels and Goldstein (1976) have correctly admonished users against the unsystematic application of performance measures. They point out that measures must be selected which: (a) tend to eliminate redundant information, (b) are sensitive to skill changes which occur during training, and, (c) have performance predictive qualities. They presented a method for selecting measures based on multivariate statistical models, which evaluate the total set of candidate measures.

In addition to the problem of unsystematic application of measures, another misstep that must be avoided is the application of approaches developed for other purposes. Most previously developed or proposed models simply apply sets of measures. Sophisticated approaches to a selection of measures, and statistical reduction of data have been developed, yet the evaluation approach itself remains basically unstructured. (References a, c, d, and f). Two major obstacles are manifest in these approaches. First, the measures that are available tend to be directed

COMMAND/EVALUATOR

AVAIL.	EARNED	
		COMMAND/EVALUATOR - GENERAL
10		Was SAU Commander aware of tactical employment of all units under his command?
10		Was a low noise level maintained in CIC?
10		Was classification a continuous process by SAU Commander?
20		Were four weapon attacks successful? (An urgent attack does not need to be a hit in order to be considered successful.)
		APPROACH PHASE
8		Was Datum properly disseminated to all units?
6		Was SAU properly formed up, and was spacing correct, considering predicted sonar range?
8		Was SAU search front properly re-ordered and was approach to Datum proper for tactical situation?
6		Were Cone of Courses, Intercept Course, and time to enter TDA compared and concurred with Assist Ship?
6		Were appropriate countermeasures executed during Approach Phase?
8		Were Plans Red and Black and Weapons Policy passed to Assist Ship?
8		Was controlling station properly kept informed?
6		Were aircraft plots evaluated to determine target course and speed?
8		Was time to enter TDA updated with latest contact information and new Intercept Course executed accordingly?
5		SWAP SITREP requested and obtained prior to execution of SWAP.
5		SWAP SITREP disseminated to command, with State, Weapons, Contact status, and Datum information included.
7		SWAP executed in a timely manner.
5		SAU advised when SAC is assumed.
8		Zig-Zag Plan executed prior to entering TDA.
6		Appropriate Material Countermeasures prepped or executed.

Figure 1. ASW Escort Qualification Program Evaluation Form

towards measure of individual skills. The interpretation of such measures with respect to tasks which are interrelated between groups of individuals is elusive. Secondly, previous models tend to assume the training exercise in question is a complex integrated and continuous task. Therefore, measures are selected (usually for post exercise critique) which attempt to summarize aspects of performance throughout the entirety of the exercise. The danger of such an approach has been incisively described (Vruels and Goldstein, 1976).

> "Measures which are not useful for one condition, but which are 'carried along' to cover a second condition, might degrade the power of the set to describe the first condition. Thus, one must be cautious in the application of universal measure sets to cover a variety of task situations."

The unsatisfactory applications of previous approaches illustrate that performance measurement methodology for team training needs more development. For this reason, we must first start by addressing the requirements for ASW team training.

APPROACH

Requirements for ASW Performance Measurement

ASW team training exercises such as those using the 14A2 trainer, train several subteams, including CIC, UB Plot, Sonar and Air Control. Training is directed at the development of coordination of operational procedures, and communications both within and between subteams. Tactics is taught at a team level. Different exercises address divergent training objectives, such as ASROC Weapon Delivery, ASW Escort Missions, and ASW Helo Vectored Attack exercises. These exercises, in turn, may be divided into discrete phases such as: Approach, Search, Tracking, Attack, Post Attack, and Lost Contact. Phases commence and are terminated by key events, such as contact, weapon assignment, etc., which define the conditions within a phase. Task requirements can be significantly different in various phases. Significant variables effecting performance, in ASW training, include environmental conditions, complexity of target submarine maneuvers, and (simulated) malfunctions. The team must be exposed to and trained to handle these varying conditions.

The complexity of the ASW combat readiness precludes a more comprehensive discussion of the training problem within the scope of this paper. However, the requirements for performance measurement can be briefly summarized as follows:

1. The set, or composite of quantitative performance measures must be comprehensive, and based on observed or computer recorded data (qualitative data should be avoided).

2. The set of measures must provide valid contributions to team performance evaluation (sensitive to performance change).

3. The set must define performance in a manner such that specific performance needing improvement can be identified (avoid loosely defined parameters).

4. The set must be readily modifiable to reflect the training objectives of different types of exercises.

5. The set must include performance measures from all phases of the exercise.

6. The set must include measures of team, subteam, and individual performance.

7. The set must be adaptable to different levels of complexity in several exercise variables.

8. The set of measures must be subject to weighting which reflects the user's desired emphasis of the various factors of performance.

Preliminary Concept for an ASW Team Performance Measurement Model

Attempting to devise an approach for a Performance Measurement Model that meets the requirements previously discussed above, has led Honeywell to adopt a three-dimensional matrix model as illustrated in Figure 2. The first dimension represents individuals, which in turn, are grouped into subteam blocks. The second dimension represents categories of measurement, which includes: (a) procedures, (b) communications, (c) accuracy, (d) tactics and, (e) time. The results of our analysis indicates that most meaningful measures of ASW team training fall within one of these categories. The third dimension represents phases of the training exercises. Any specific exercise may consist of one or more phases depending upon training objectives. Thus, performance measures are referenced to specific subteam/phase/category problem components which are designated as cells.

Each cell limits the area of measurement to a specific operational definition. Therefore, very specific quantitative performance measures can be developed with highly definitive meaning and interpretation. Each

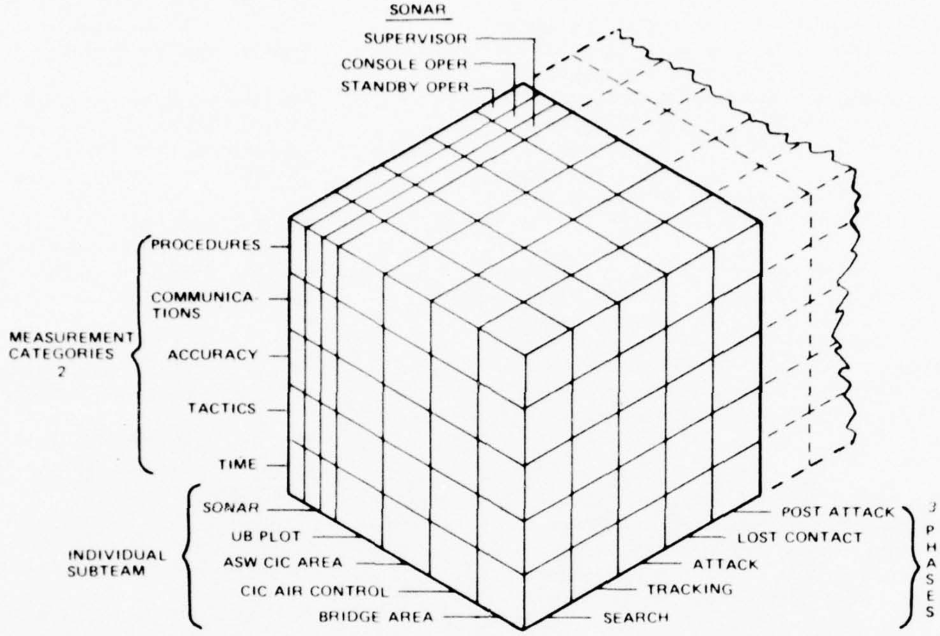

Figure 2. Three-Dimensional Matrix Performance of Measurement Model

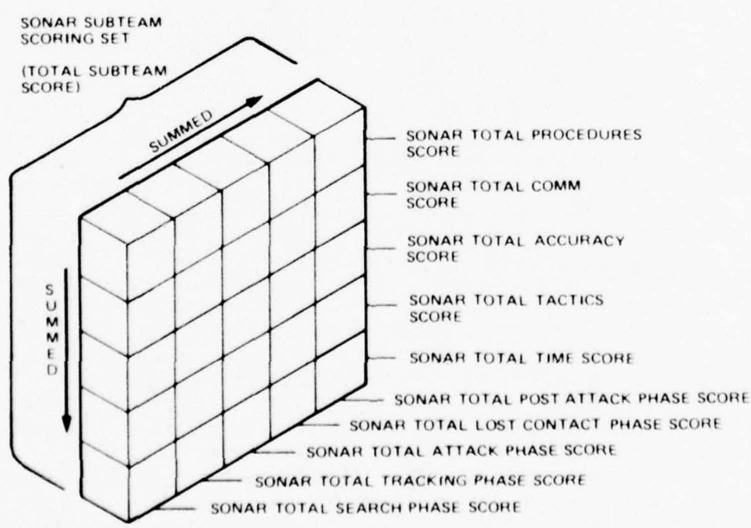

Figure 3. Individual Subteam Scoring Composite

measure addresses a specific performance in a specific phase or task condition. While it is not necessary or even intended that a quantitative measure can be developed for every cell, partitioning into cells enables many measures to be used which would be inappropriate if they were interpreted as measures of total problem, total phase, or total subteam performance.

Combining Performance Measures

Individual performance measures can be used for feedback to the trainees, but they cannot be directly combined to represent performance at a broader level of performance evaluation. Given the quantitative measures for all appropriate cells, composites of these measures must be summated to provide an evaluation by categories, phases, and personnel levels. This summation is possible when individual measures are transformed or converted into standard scale scores ("Z" scores, for example). The total of all individual cell scores represents the total team score. Although the total score summarizes the total team performance level, it is not sufficiently descriptive.

The set of individual cells may be combined into three major composite groups. These composites are:

1. Subteam Composite Scores
2. Exercise Phase Composite Scores
3. Measurement Category Composite Scores

Figure 3 shows an example of the composite of cells for the sonar subteam score. This score represents subteam performance across all phases and categories of measurement. The total composite can be divided into subsets by summing across rows or across columns. Scores summed across rows provide subteam scores by measurement category, i.e., Sonar Procedures Score, for all phases. Scores summed across columns generate subteam scores in all categories, for a specific phase, i.e., Sonar Attack Phase Score.

An example of a Composite score by Exercise Phase is illustrated in Figure 4. The Phase Composite Scores represents the total team score for the designated phase taking into account all subteams and categories of measurement. Subsets of scores summed in rows results in a team score for each category with respect to the phase represented by the composite. Summation of the column subset of scores gives subteam scores for all categories within that phase.

An example of the Measurement Category Composite Score is depicted in Figure 5. The composite is the team score for all phases in the procedure category of measurement. Examination will show that subsets of scores within this composite yield redundant information obtained by the subsets of scores previously described.

The capability of the model to provide a set of scores by column and row, a composite score by subteam, category or phase and a total score for all cells offers a unique opportunity to evaluate team performance and select new problems. For example, if a team is weak in communication, during the lost contact and attack phase, a problem can be selected (or modified) to provide extra practice in these phases with team concentration in improving communication. Similarly, if the team is weak in tactical coordination a problem with this emphasis can be selected. In general, the proposed methodological approach can provide an average comparative score and part scores showing the particular strength and weaknesses of each team.

Measurement Techniques

The measurement of performance for each cell described above depends upon the ability to detect the performance involved. Obviously the computer can measure all performance results which interact with the program, but many other very desirable and necessary performance measures are not available to the computer. These team performances must be observed and measured in some way by an instructor or problem monitor. The following discussion identifies the computer versus monitor requirement for each performance category.

- Performance Monitoring

  One of the primary objectives of ASW team training is teaching trainees to follow and practice the established procedures for their tasks. The following of established procedures or doctrine helps to assure effective team performance. Procedure following, as considered here, consists of console and equipment operations, manual operations involved in plotting, status board updating and log keeping. Procedures in conducting communications are covered in the separate communications category.

  For the purposes of evaluation and training, all incorrect procedures should be detected so each occurrence can be recorded and weighted for criticality. Feedback to the team is necessary for correction.

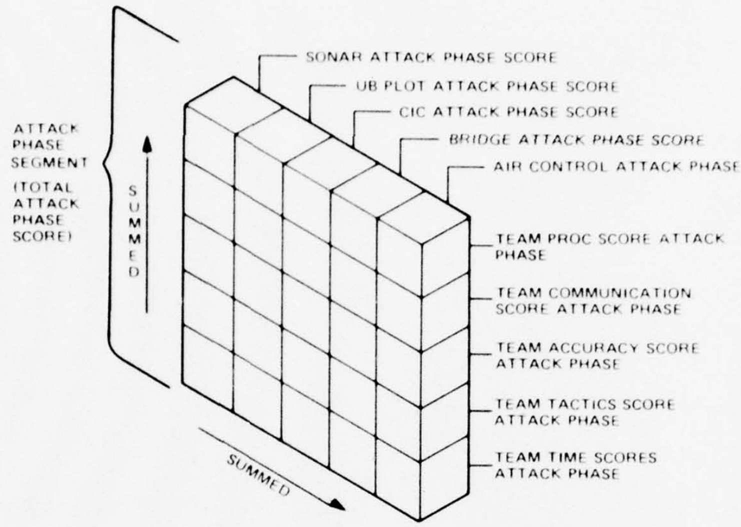

Figure 4. Exercise Phase Scoring Composite

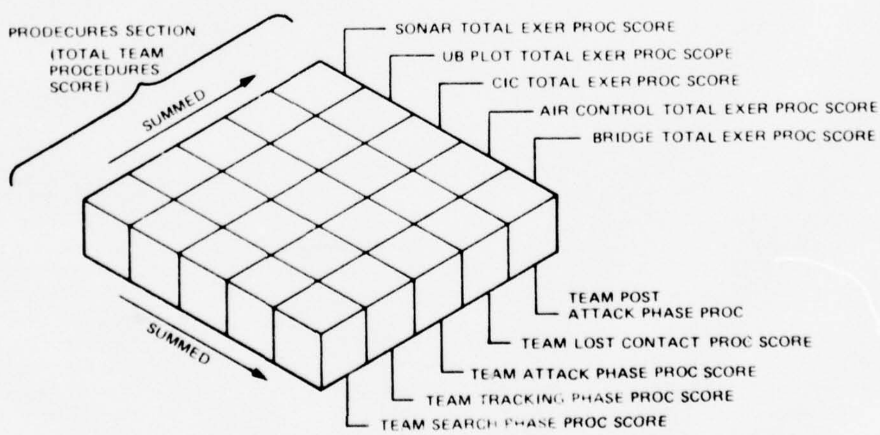

Figure 5. Measurement Category Scoring Composite

The detection of procedural errors by the computer can be accomplished if two requirements are met. These are:

1. The switch position or equipment operation must be sensed by the computer.

2. A standard problem, or portion of a standard problem, must be used so the doctrine procedure can be programmed for comparison.

In dynamic exercises where the team and computer interact and react, the number of doctrine switch settings which can be predicted is severly limited. The number of possible choices available to the operator must be limited by structuring the problem.

In these dynamic situations, an observer can be more effective. A well trained observer can monitor the operator's actions and record the error, time of occurrence and criticality. These equipment operator procedural errors can be combined with the other observer detected errors such as manual errors which are not available to the computer, i.e., manual plot entries. All such errors should be detected and included in the team performance evaluation. It should be noted here that the number of procedural errors will be more useful as a score than the number of correct actions. This count will then include both errors of omission and commission and will be much more useful in calling specific errors to the attention of the team for correction.

The need to weight errors in terms of significance is also a possibility. Weighting of scores in terms of criticality, or effect on mission success could affect the team score but would be of less importance in feedback to the team for correction.

When the procedural error score is within a satisfactory tolerance, training on procedure following can be considered as complete.

- Accuracy Measures

Most measures of operator and team performance accuracy can be obtained by the computer. In fact, the computer is ideal for recording and making operator accuracy measurements. These measurements can include a great number of positioning, tracking and switch setting actions which are a measure of operator skill. Such measurements can be made periodically at one second, ten seconds or one minute intervals for continuous operations or when specific events occur. When continuous operations are involved, a beginning and an ending event is required to prevent making measurements at inappropriate times. For example, for sonar cursor positioning, accuracy should not be recorded before contact nor after time of fire.

In addition to the computer recorded accuracy measurements, some accuracy measurement may need to be made by the instructor or observer. Manual plotting accuracy is one such example which is normally not available to the computer for measurement.

The evaluation of accuracy measurements can also be made by the computer. The accuracy of a specific team can be compared by the computer with the accuracy of other teams, with a fleet criterion or with allowable tolerance bands. These comparisons are necessary for an evaluation of "how good" or "how bad." This information, as well as the raw accuracy data, should be supplied to the team as feedback and reinforcement. The actual measurement and when it occurred, can help the operator to improve performance. Graphic data can show trends, time of errors, variability of performance and bias. This specific data can be most beneficial for operator and team training and improvement.

- Communication Measures

The current practice for team evaluation as shown by the ASW Escort Qualification Report, Figure 1, is heavily weighted with communications between various team members. Over 50% of the specific evaluation entries relate to oral reports or involve communication between team members.

Unfortunately, computer interpretation of the spoken word is not yet feasible so observers must be used to sense and evaluate the communication between various members of the team.

As in the case of procedure following, the detection and scoring of communication errors only is the preferred approach. This approach assumes that most communication will be appropriate, correct and will occur at the proper time. The observers can then concentrate on obvious errors which require correction. These errors can be classified under the following types and examples for team evaluation and scoring:

1. Errors in transmitted data, i.e., true bearing reported when relative bearing is correct.

2. Missed information report, i.e., target doppler not reported.

3. Improper communication procedure, i.e., non-doctrine choice of words or sequence of data.

4. Unnecessary communication, i.e., irrelevant comments or criticism during the problem.

If the observer can record and count these type of errors, a high count would obviously indicate the need for more training. Similarly, a low count would reflect the performance of a well trained team.

- Timing Measures

The time required by a team to accomplish a specific result is a significant indication of team performance. A minimum time score usually indicates efficiency, effectiveness and absence of errors. Team scores can be a very useful summary indicator of the skill level of teams.

Timing measures require a beginning event or signal and a terminating event or signal. These signals may be detected directly by the computer or may require a cue from the monitor. The computer records the time of the event and records the elapsed time as the measure. This time period can then be compared for team, individual, and problems.

To be meaningful the team scores should only be used under standard problem conditions. When the initial problem conditions are identical, and carefully controlled, the variation in time between individuals or teams is due primarily to the skill level. It is assumed that the shorter the time required to reach the objective, the higher is the skill level of the team.

- Tactics Measures

The measurement of the tactical moves made by a team in a given problem situation and the subsequent evaluation of these moves in terms of tactical effectiveness, adherence to doctrine and training, is in a different dimension than the previous measures. It is obvious that tactics is a significant factor in the overall performance of the team and in the evaluation of the team. However, the rationale and techniques which may be used for tactics measurement requires a more sophisticated approach than described above.

Our current effort, in conjunction with Decision Sciences, Inc., of San Diego, California, is the use of a Game Theory Approach which evaluates adversary tactical maneuvers. This effort is in the early stage of development and results are not available. However, it is anticipated that numerical values will become available. These numerical values will be converted into scores and combined with the team scores described above for a total team evaluation.

- Results to Date

The ASW Tactics Team Trainers, located at Fleet ASW School at San Diego, California, have been programmed to provide computer printouts of problem data. The initial approach has been to print out all data in the data base once each second for analysis. The data for several pilot exercises were collected and analyzed in detail.

Data for tactics evaluation and communication was not collected. Procedure following and timing data were available but meaningful evaluations could not be made. Accuracy measurements, however, proved to be very interesting. Figure 6 shows the sonar cursor bearing error from contact for a typical problem. Notice the magnitude of the error and the constant "lead" errors. Figure 7 shows sonar cursor range error for the same problems. Note the constant range error which shows a range lag on a closing target. Figure 8 shows a comparison between three runs on bearing error. Note the large variation between runs and also the constant "lead" error. Figure 9 shows similar data for comparative range error. Again the variability between runs is evident as well as the constant range error.

The continuing effort will result in data on a larger number of teams as well as on a larger number of parameters. These data, together with observations by monitor personnel, will provide the necessary data for trainer evaluation and application of CAI.

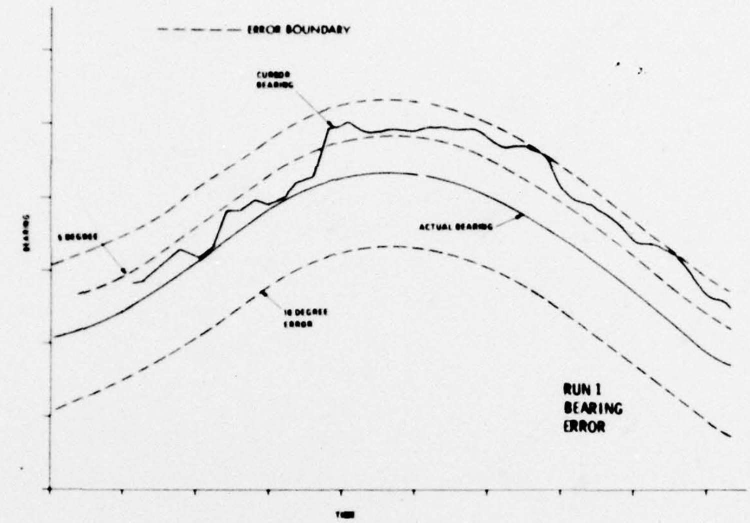

Figure 6. Run 1 Bearing Error

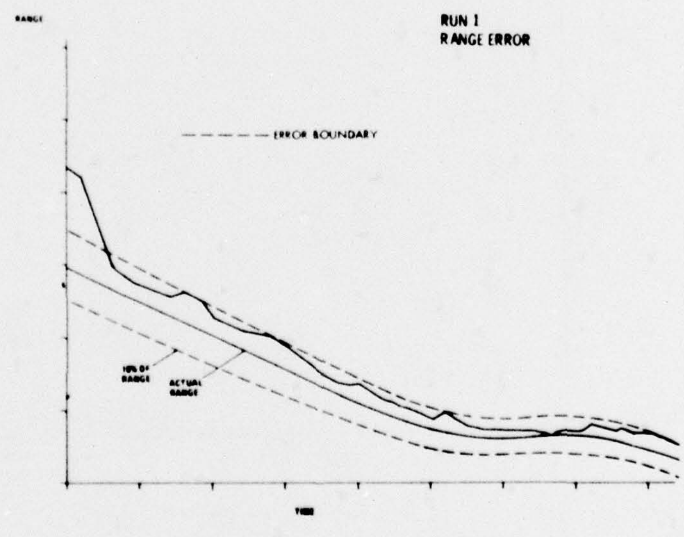

Figure 7. Run 1 Range Error

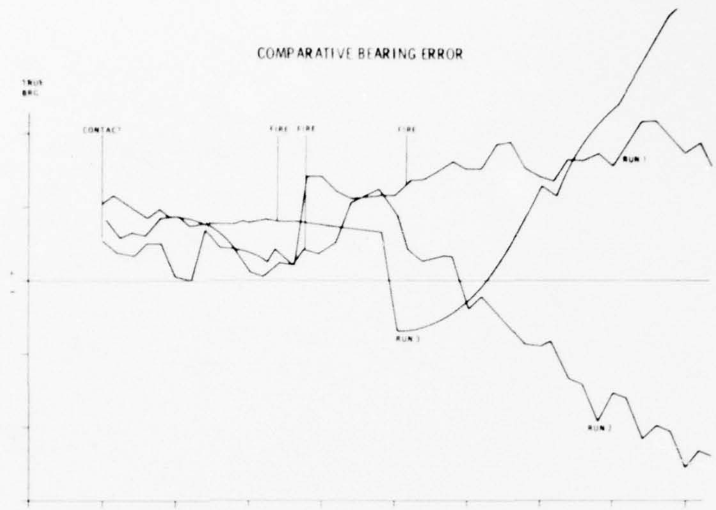

Figure 8. Comparative Bearing Error

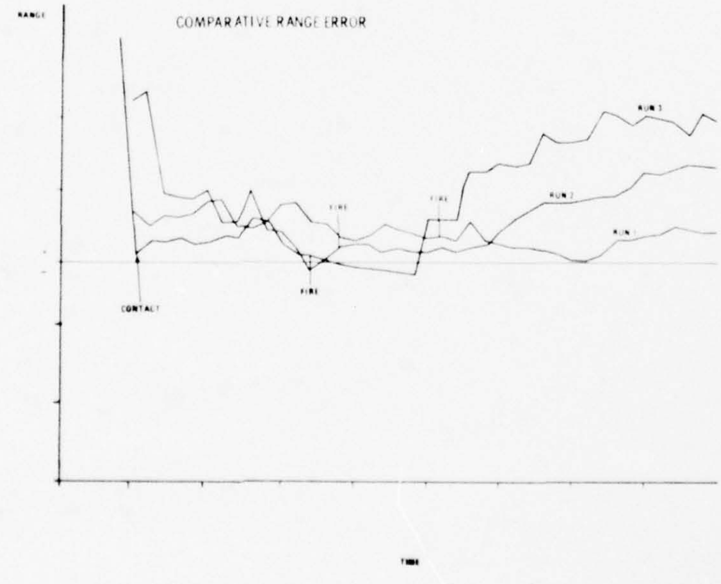

Figure 9. Comparative Range Error

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DIGITAL COMPUTERS IN TRAINING DEVICES: TRENDS AND FORECASTS

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SUMMARY

The role of the digital computer is greatly increasing in both weapon systems and the training equipment used to simulate those weapon systems. The astonishing advances in computer technology over the past few years have multiplied the capability of effectively simulating the many weapon systems used by the modern military forces. The objective of this paper is to bring into focus the impact of the digital computer technology on training equipment and to present trends and forecasts of computer hardware and software used in training equipment.

INTRODUCTION

Because of their ability to solve the pertinent equations in real-time, analog computers were used in early training devices to simulate the behavior of the various vehicles in a tactical situation. The analog computer-activated training devices were very effective. However, the lack of flexibility and limited accuracy of the analog computer imposed limitations on the modeling of weapon systems.

In 1952, the Naval Training Equipment Center sponsored a study by the University of Pennsylvania in digital simulation. The specific goal of the study was to determine if a digital computer could be used as a substitute for the analog computer in an operational flight trainer. The resulting report specified a Universal Digital Operational Flight Trainer Tool (UDOFTT).[1] UDOFTT was constructed by Sylvania and became operational in 1959. This constituted the first practical step in the application of digital technology to training simulation. Some of the favorable characteristics of the digital computer include programming and model solution flexibility, greater accuracy over a range of scales, ability to develop hardware and software independently, and the ability to use the digital computer for testing the entire training device.

Advances in digital computer technology have resulted in vital importance being placed on the use of the general-purpose digital computer as a basic tool in the field of simulation. The digital computer has contributed immeasurably to the enhancement of the technical characteristics of training equipment by increasing the fidelity of simulation and improving reliability by the reduction of electromechanical components. The expanding capabilities of the digital computer hardware have resulted in a more intricate training device which enables improved simulation of operational environments. The capability to update configurations and introduce a variety of tactical scenarios through computer programming without requiring modifications of hardware has become a reality. The digital computer now forms the "heart" of the modern training devices.

TRAINING DEVICE DIGITAL COMPUTERS

In order to put the training equipment Digital Technology in its proper perspective, it is necessary to examine the current number of digital computers in the Cognizance Symbol "20" inventory. In November 1965, only 15 general-purpose digital computers had been installed in the NAVTRAEQUIPCEN's training devices. Only five programming languages were required for the seven models of computers involved. Today, in contrast, the majority of the larger vehicle simulators presently being procured are activated by general-purpose digital computers. Even the smaller devices that once used analog servomechanisms are being manufactured using programmable microprocessors.

The current NAVTRAEQUIPCEN inventory consists of 587 general-purpose digital computers of 66 different models either installed or under contract. This complement consists of 50 second generation, 449 third generation, and 38 fourth generation computers. The computers are programmed in 40 different languages and are used to activate 296 devices of 112 different types. The training devices and their associated computers require approximately 3,600 software programs and associated documentation. Table 1 presents a summary of the growth of digital computers in Cognizance Symbol "20" training equipment from 1965 to January 1977. Table 2 lists the computers by computer manufacturer, showing the quantity of computers installed or under contract. The increasing number of general-purpose digital

TABLE 1

SUMMARY OF DIGITAL COMPUTERS IN TRAINING EQUIPMENT
(Installed or Under Contract as of 11 Jan 1977)

	NOV 65	NOV 67	NOV 68	NOV 69	SEP 70	APR 71	MAY 72	SEP 74	OCT 75	JAN 77
GP Computers	51	83	108	115	157	177	269	336	405	587
2nd Generation Computers	43	51	50	55	53	54	54	51	51	50
3rd Generation Computers	8	32	58	60	104	121	213	274	339	499
4th Generation Computers	0	0	0	0	0	2	2	11	15	38
Computers Out of Production	0	0	0	9	10	12	13	14	17	210
Computer Models	14	18	20	20	23	27	35	41	48	66
Computer Manufacturers	7	7	9	9	10	12	13	14	17	20
Programming Languages	11	12	13	13	17	20	25	28	34	40
Computer Programs	750	1000	1050	1100	1300	1500	1900	2300	2700	3600
Device Types	12	26	27	30	84	41	56	76	97	112
Number of Devices	43	62	79	85	89	104	131	163	189	296

TABLE 2
GENERAL-PURPOSE DIGITAL COMPUTERS
INCORPORATED IN COGNIZANCE SYMBOL "20"
TRAINING EQUIPMENT

NOTE: An Asterisk (*) precedes the Operational (Weapon System) Computers used in Training Equipment.

MANUFACTURER / COMPUTER	QUANTITY INSTALLED OR UNDER CONTRACT
Computer Signal Processors, Inc.	
CSP-30	9
Control Data Corp.	
CDC-3100	1
CDC-1604B	1
*CDC-5400C	4
*CDC-5400L	2
Data General	
NOVA 210	1
NOVA 800	17
NOVA 1210	1
NOVA 1220	1
Super NOVA	1
Digiac Corp.	
CT-10	75
Digital Equipment Corp.	
PDP 8/E	1
PDP 11/05	4
PDP 11/15	1
PDP 11/35	2
PDP 11/45	89
PDP 11/50	2
General Precision	
GP4	4
GP4B	3
Harris (Datacraft)	
DC-6024/1	4
DC-6024/4	6
DC-6024/5	11
Hewlett Packard	
HP 2100A	5
Honeywell	
H-316	11
H-716	23
H-800	2
DDP-24	13
DDP-116	1
DDP-124	13
DDP-224	4
DDP-416	5
DDP-516	82
IBM	
*AN/ASN-91 (IBM TC2)	2
*AN/ASQ-155 (IBM 4-PI)	2
*AYA-6 (IBM 4-PI)	3
Interdata	
Interdata 6/16	20
Interdata 7/16	2
Interdata 8/32	11
Litton	
*ASA27A (L-304)	3
MicroSystems, Inc.	
Micro-810	4
Raytheon	
PB 250	4
RAY 704	3
RDS 500	2
Sperry	
*AN/AYK-10 (Univac 1832)	7
AN/UYK-7	8
AN/UYK-20	6
CP-642A	5
CP-642B	2
*CP-901	5
UNIVAC 1230	6
UNIVAC 9300	1
Sylvania	
CP-642B	2
Systems Engr Lab	
SEL-32/55	22
SEL-85	1
SEL-86	4
SEL-810A	1
SEL-811	5
SEL-840A	1
Varian Data	
Varian 72	4
Varian 73	8
Varian 620I	1
Westinghouse	
*AN/AWG-10A Computer	3
Xerox Data Systems	
SIGMA 3	1
SIGMA 5	30
XDS-530	1
XDS-930	8

computers substantiates the fact that we have entered a period of major reprogramming requirements. It is realistic to assume that the use of digital computers in training devices will continue to accelerate as shown in Figure 1. If the present trend continues, there will be in excess of 1,100 general-purpose digital computers used in training devices by 1981.

The growth in the number of general-purpose digital computers has presented logistic support problems. Factors contributing to the burden of training equipment support includes the increase in the number of programming languages, the increase in the number of different computer models, increase in the number of computer manufacturers, the increase in memory size of the computers, and the increase in complexity of the weapon systems being simulated. Growth trends for the number of programming languages, variety of computer models, and the number of computer manufacturers are shown in Figure 2.

The increase in computer memory size requirements and the complexity of the weapon system being simulated is demonstrated by comparing one of the earlier digital computer activated training devices with a present day system. The device 2F66A, S-2E Weapon System Trainer, was delivered in 1966 with a PB-250 computer containing 5,120 words of memory. Device 14B49, S-3A Positional Trainer, was recently delivered with 13 PDP 11/45 computers, 3 CSP-30 computers, and one AN/UYK-10 computer. One of the PDP 11/45 computers contains approximately 94,000 words of memory. Device 2F101, T-2C Operational Flight Trainer, represents a typical modern training device. This device contains four PDP 11/45 computers, each with a capacity of 48 thousand words of core memory. In addition to the core memory, each computer can access a 500 thousand word disc to obtain utility and diagnostic programs, to retrieve overlays from disc, and to load the main trainer program from disc.

MICROPROCESSOR TECHNOLOGY IN TRAINING EQUIPMENT

Large-scale integrated circuits in the form of microprocessors, semiconductor memories, and logic arrays are now being utilized in training equipment. This latest evolution in technology is the result of the efforts made by major semiconductor suppliers to gain a share of the computer market. Microprocessors have been readily available for about 4 years. Microprocessors and

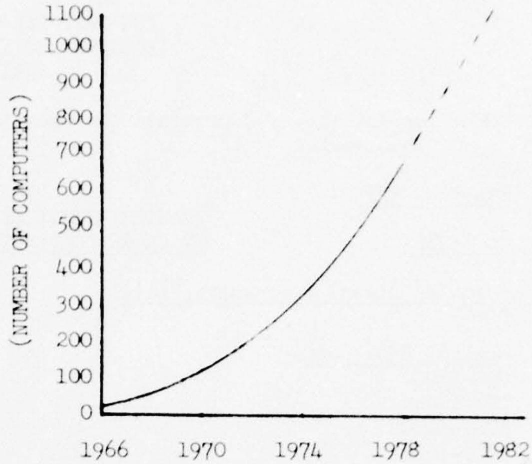

Figure 1.
Growth of Digital Computers Used in Training Devices

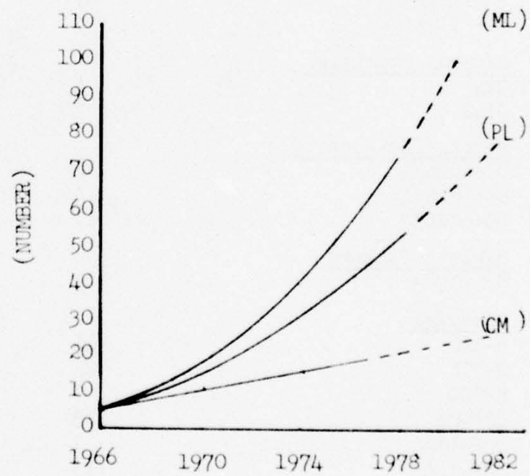

Figure 2.
Computer Manufacturers (CM), Models (ML) and Programming Languages (PL) Used in Training Devices

associated chips are being used in the following training devices:

a. Devices 15G14, 15G14A, and 15G14B are GCA Moving Radar Target Generators. Each device uses a programmable microcomputer as the heart of the system. There are approximately 170 of these devices under contract.

b. Device 14E27, Shipboard Acoustic Processor Trainer, contains a general-purpose computer which controls a function generator. Tables are used in the generation of various trigonometric function and pseudorandom number generators. The tables have been preprogrammed by the contractor in programmable ROMs.

c. Device 2F112, F-14A Weapon System Trainer, includes a SEL 32/55 computer and a CDC 5400 computer that accepts airborne operational tapes which are adapted to the trainer. A microprocessor is utilized to interface the SEL 32/55 computer to the CDC 5400 computer.

Microprogrammable computers, utilizing microprocessor technology, are also beginning to appear in training devices. Examples of microprogrammable computers used in training devices are:

a. Device 2B34A, S3A Weapon System Trainer Visual Attachment, and Device 2F106, SH-2F Weapon System Trainer Visual Attachment, utilize a Varian 73 microprogrammable computer as the heart of the trainers. The Varian 73 operation code set consists of the Varian 620I Operation code set programmed in a ROM memory.

b. Devices 7B1/1, Electromagnetic Stimulator; 10A3/1, ESM Trainer; 10A3/2, ECM Trainer; and 10A3/3 Electronic Warfare Signal Practice Trainer each utilizes a microprogrammable HP2100A computer as the central part of the trainer.

Microprocessors and microcomputers are presently supplementing the conventional minicomputers and midrange computers in many applications. It is anticipated that microprocessors will experience heavy utilization in smaller devices that were designed using analog equipment in the past years. Switching speed and support problems for microcomputers are preventing them from replacing the minicomputers and larger computers in training equipment on a significant scale at the present time.

Microprocessors remain the "hottest" design subject in electronics, and are likely to remain such for some time. However, the boom of the microprocessors does not come without some problems. The software support of the microprogrammable processors will be done by a designer/programmer. The designer/programmer will implement his design, previously accomplished with hardwired logic, through on-line programming of the microprocessor. Instead of using AND, OR, NAND, and NOR logic gates, the designer/programmer will use mask, compare, and jump instructions. Most microprocessor applications require a mixture of control operations and application computations which are interleaved in the body of the program. Personnel without a background in both hardware and software will find this type of programming extremely difficult.

The small memory utilized by most microprocessors and a lack of peripheral equipment will tend to hinder software development and software support of microcomputer-based training equipment. This problem can be partially alleviated by using either hardware simulators or software cross-assemblers and editors on larger machines.

The future development of complete system software by the microprocessor manufacturers themselves is doubtful. Most likely, the future development of system software will be left to the software houses. This will result in the designer being faced with developing his training device software on crude systems with clumsy input/output devices and with little software to support him. Vendor support for micros is far less than that available for most of the minicomputers on today's market. The designer and the support personnel will consume a considerable amount of additional time discovering for himself the answer to his questions.

A major area of concern is the logistic support problems caused by a proliferation of hardware microprocessors, microcomputers, and software assembly languages. New specifications and changes in some of the Data Item Descriptions will be required to provide a supportable training system to the user.

SOFTWARE FOR TRAINING DEVICES

With the extensive math modeling required in today's training equipment, the development and mechanization of algorithms has become extremely complex. Computer software support is a major area of expense for training equipment and the modern day weapon systems. As greater precision and flexibility are demanded by weapon systems, new kinds of hardware become available, and

budgets and manpower shrink, training equipment software will become even more important in the future than it is today.

The rising costs of training equipment computer software have become a matter of concern in recent years. The actual magnitude of computer software costs and how to control them have been subjects of increasing attention by managers in both the Department of Defense and Industry. These concerns led to the Assistant Secretary of Defense (Installation, Logistics, and Controller) and the Director of Defense Research and Engineering establishing a joint Software Steering Committee. The charter of this committee is to find methods for controlling increasing costs, improving the quality, and minimizing the adverse impact of poor software performance on weapon systems effectiveness.

An Air Force sponsored study, Information Processing/Data Automation Implication of Air Force Command and Control Requirements in the 1980's (CCIP-85) provides quite an extensive analysis of computer software. Although the report (CCIP-85) deals only with the Air Force software, the findings are fairly representative of other services. During fiscal year 1972, the Air Force invested somewhere between $1 and $1.5 billion on computer software, compared with $300 to $400 million for computer hardware.(2) Software represented 70 percent of the 1972 Air Force investment in ADP systems.

A study was made during 1974 by the Institute for Defense Analysis concerning Automatic Data Processing (ADP) costs in the Defense Department (DOD). Reported costs, plus burden, provided a figure of $2.3 billion for ADP costs in Fiscal Year 1973. This figure was extrapolated to cover the reported and nonreported cost of all DOD computer systems and is shown as Table 3.

A symposium held at the Naval Postgraduate School in September 1973 concerning software was sponsored by the Office of Naval Research, the Army Research Office, and the Air Force Office of Scientific Research. Figure 3 was extracted from the proceedings of the symposium and shows the likely trends in the relative costs of hardware and software. In the late 1950's the software was only 20 to 30 percent of the cost. At the present time, software is from 70 to 80 percent of the total system cost. During the 1980's, software cost will continue to rise until it reaches 90 percent of the total system cost. The relative importance of software maintenance is reflected by the overlay on Figure 3. Approximately 60 percent of the total hardware/software dollar will be going into software maintenance by 1985.

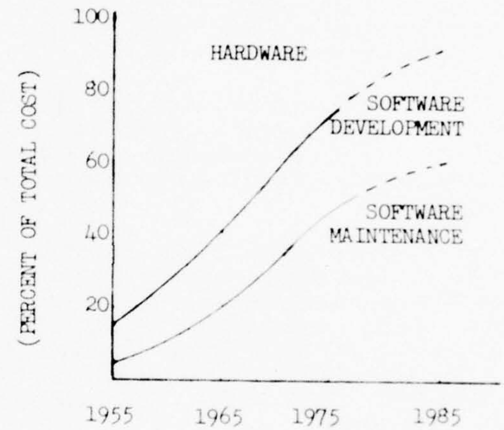

Figure 3.
Hardware/Software Cost Trends (4,5)

TABLE 3. TOTAL ADP COST ESTIMATES IN 1973(3)

	Air Force	Army	Navy	Other DOD	DOD Total
Software	$1.0-$1.3	$0.7-$0.8	$1.0-$1.3	$0.2	$2.9-$3.6
Hardware	$0.4-$0.5	$0.3	$0.3-$0.5	$0.1	$1.0-$1.4

(dollars in billions)

NOTE: Individual entries do not sum to total because of rounding.

The hardware/software cost trends for training equipment appears to be similar to that experienced in other DOD Weapon Systems. Experience at the NAVTRAEQUIPCEN shows that the initial cost of software runs from two to three times that of the computer hardware.

The discussions above pertain to the direct cost of software. The indirect costs of software are even greater. During the 1972-73 time frame, it cost approximately $75 per instruction to develop Air Force Avionics software, but the maintenance of the software has cost up to $4,000 per instruction.(6) The cost of maintaining much of the older software products is an order of magnitude larger than production cost, due to poor design, structure, and production control. Programming costs also increases drastically when either memory capacity or memory time is nearly used up.

Because of the increasing amount and high cost of software required for training equipment, it has become necessary to emphasize software development, maintenance, and modification. The Department of Defense agencies have funded a number of studies and held conferences concerning the problems encountered in software development. The most prevalent problem among those identified in software development is the undisciplined approach which is generally taken. When undisciplined approaches are utilized in designing and implementing software, the resulting software systems often become a nightmare for the software personnel. Undisciplined implementation of software also impairs the usefulness of software design reviews.

Today's software community spends entirely too much time in testing and debugging software and not enough time designing it. The average cost of analysis and design for software production is 32 percent of the software cost; the coding and implementation averages 24 percent of the software cost; and checkout and test averages 44 percent of the total cost spent for software production. Approximately 50 to 70 percent of the checkout and test cost is incurred because of bugs left in from the analysis, design, and implementation phase. The greatest opportunity to obtain improved software at a reduced life cycle cost is through improved analysis and design techniques. For systems as complex as our digital computer controlled training equipment, only a clean and compelling design will prevent the computer program from becoming a mass of confusion and frustration.

Many companies are moving toward utilization of structured techniques in an effort to develop a disciplined approach to software design. While the companies practicing structured programming are still in minority, there has been a relatively wide-spread utilization of this technique. One of the largest projects to use structured programming techniques was the mission simulation system used as part of the Skylab operations. Approximately 400,000 lines of source code were produced using this technique. The results were significantly higher productivity than that previously experienced using conventional techniques.

Structured software design is not a "cure-all" for the ills of training equipment programming; however, it could be a positive step in reducing the life cycle cost of software. Structured software should be easier to understand, debug, and maintain than conventional software.

There are other technological areas in which research is being conducted. The Department of Defense is sponsoring attempts to develop "automatic programming systems"(7,8) to replace the functions that are currently performed by programmers. Automated Aids have been developed to support top-down structured programming. A Code Auditor program for Automated Standards compliance checking is another software development aid of recent interest. Some of these new technologies have potential application to reducing the cost and improving the quality of training equipment software systems.

The majority of the training devices are programmed in assembly language. Several of the trainers are programmed utilizing either the CS-1 or CMS-2 programming language. Some of the current training device programs have been developed utilizing FORTRAN Modules.

The University of Florida has investigated the characteristics, syntax, and constructs of a high-order language for real-time trainers. This work was performed under contract to the NAVTRAEQUIPCEN. The report prepared as a result of the study was titled "Real-time PASCAL." Real-time PASCAL is an enhancement of the regular PASCAL language and retains the style of PASCAL.

The Department of Defense has established a standard high-order language working group. The goals of this working group were to formulate requirements for a standard high-order language, evaluate

existing languages, and recommend implementation and control of a minimum set of common Department of Defense high-order languages. The formal high-order language requirements have been established and documented.(9) PASCAL was one of three base languages recommended by the working group. This was of particular interest since the University of Florida's Real-time PASCAL was PASCAL based. This provides a degree of confidence that the new Department of Defense standard high-order language will provide the solution to the NAVTRAEQUIPCEN's high-order language problem.

COMPUTER TECHNOLOGY FORECAST

Enormous progress has been made in the area of computer hardware during the past 25 years. At times this progress has been revolutionary in nature. It is not anticipated that there will be major revolutions in the hardware technology during the 1980's. One of the major reasons that the computer architecture has not radically changed during the past and is not expected to radically change in the future is the large investment that the computer manufacturers have in software. There will be many improvements in hardware technology but primarily in areas that will not affect software compatibility or require radical rewriting of operating systems, supervisors, and other type of utility software.

The magnetic core remains the most popular primary memory in the Navy computer inventory. This is primarily because of its reliability and nonvolatile nature. The magnetic disk is the most popular secondary (mass media) memory utilized at this time. The cost of logic and integrated circuit memory is decreasing at such a rapid rate, it would appear that the integrated circuit memory will replace the disk as the secondary mass memory media. However, disk is about one and one-half orders of magnitude more dense than the integrated circuit memory and about three orders of magnitude cheaper.(10) It is anticipated that the disks will improve as fast as the integrated circuits memory.

The Charge Coupled Device (CCD) has presently gained an entry into the secondary memory market. The CCD's are somewhat similar in operation to the delay line memory and are volatile. As with other volatile memory, an auxiliary power source can be incorporated into the unit enabling the user to restart his program without having to reload the memory. It is not anticipated that CCD memories will become a major threat to disk memories until the mid-1980s.

It is anticipated that bubble memories will soon appear in commercial products. Bubble memories consist of a thin orthogonal film in which each bubble generated is a cylindrical magnetic domain that carries a polarization opposite to that of the film. The bubbles are about three microns in size and can be packed in densities up to 1 million bubbles per square inch.(11) Bubble memories should lead to larger and faster memories. This technology is a significant contender to the disk area since they provide nonvolatile data storage. The disk appears to be safe from this technology through the early 1980's.

The semiconductor devices that will form the mainstream computer technologies during the next decade are the complementary metal oxide semiconductor (CMOS), bipolar Schottky transistor-transistor logic (TTL), and the integrated injection logic (IIL). CMOS has high performance, extremely low-power dissipation, a single power supply, wide operating range with respect to temperature and voltage, and high-noise immunity. The advantages of TTL are low cost, good performance for a wide varity of applications, large number of established suppliers, and the fact that most design engineers are familiar with this technology. The Schottky TTL also has the edge in speed and environmental reliability. Although IIL is new, it has great potential in the future. It has the speed of the bipolar circuits, the densities of CMOS circuits, and one one-hundredth of the power consumption of TTL circuitry.

It is projected that the microcomputers will be utilized to a much larger extent in training devices during the next decade. The main areas of their use will be to supplement the present minicomputer and mid-range computer architecture, and as stand-alone computers to replace the smaller analog devices. Microprocessors will continue to replace the hardwired sequential and combinatorial logic circuits in both the digital computers and the other training equipment electronics.

To reduce some of the software cost, certain aspects of software design such as operating systems, will be incorporated into the hardware system. It is anticipated that more automatic reconfiguration and automatic shutdown and restart will be built into hardware. As the systems become more complex, there will be a tendency toward more automatic and remote maintenance techniques being utilized. Some of the remote maintenance capabilities are in computers presently being announced for marketing. It is

anticipated that training equipment will make use of these features.

Although the rate of growth of software is constantly increasing, research and development in this area has seriously lagged behind that of hardware development. The future projected growth of the computer industry is based on continuous breakthroughs in the state-of-the-art for both software and hardware. This will require reallocation of personnel, time, and funds to assure that software is properly addressed in the future.

The future applications programs will likely be far more complex than the present software. By the 1980's training equipment software packages will include programs to tutor users in the area of on-line documentation, and programs to restore and reconfigure the training device during and after hardware failure.

There will be many standard utility programs offered in firmware in the future. This will be in the form of microprocessor chips and ROM's.

In the near future, training equipment computers will have the capability to execute a high-order language directly from source code. The Modern Electronic Technology Computer MET-8 is marketed as a low cost microcomputer that directly executes a FORTRAN-like high-level language. (12)

The structured software design approach for developing system software will provide an improvement in the debugging, testing, and validation of software. On-line interactive systems will help alleviate the long turnaround time for testing. Cross-assembler capabilities on large host machines and microprogrammed emulation capabilities will provide the minicomputer and microcomputer users with some relief when maintaining assembly language software.

Software will still have to be validated and maintained in the future. The automatic production of the software for an entire system from just the statement of the problem is not projected for the near future. The advance in automatic production of software should reduce some of the maintenance activity in some problem areas. When the automatic generation of software is perfected, validation and maintenance will still be required since the generator must be validated and maintained.

CONCLUSIONS

The clearest trend of all appears to be the continuing rapid growth in the number of digital computer-controlled training equipment. Problems associated with the support of digital computer hardware and software have increased immensely since the injection of the digital computer into the training device. Factors contributing to the support problems are the increase in the number of programming languages, the increase in the number of different computer models, the increase in the number of computer manufacturers, the increase in memory site of the computer, and the increase in the complexity of the weapon system being simulated.

The computer industry has spread its influence so diversely and so rapidly that it has been heralded as a second industrial revolution. During the next few years, the computer industry will have a strong, continuous, and stable technological growth. The use of large-scale integrated chips will result in improved reliability and performance and a reduction in cost of computer hardware. The cost of computing power (cost per instruction per second) is expected to continue to decrease exponentially.

Microprocessors are increasing the accuracy, flexibility, and economy of instrumentation and control systems. These increased capabilities are opening up applications ranging from sewing machines to military avionics subsystems, such as radar, navigation-weapons delivery, and electronic countermeasures. Microprocessors and microcomputers are beginning to rapidly appear in numbers in training equipment.

The increasing demands on software will require that management become more aware of software's role in training devices. In implementing systems, it has been a tendency to give more emphasis to hardware acquisition than to software acquisition. In the future, training equipment software must have equal visibility with hardware. Without this visibility, purchasing and maintaining training equipment software will present serious problems.

In the future, new weapon systems and changes in operations to accommodate new environments and situations will necessitate major changes in the computer hardware and software that must support training equipment. The success of future training equipment thus depends on the continued development of digital computer technology.

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PLANNING AND SCHEDULING SOFTWARE DEVELOPMENT PROJECTS

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INTRODUCTION

The planning and scheduling of the resources for a project is one of the most critical activities for the success of a project. It is necessary for management to spend considerable time on this activity for a large software development project. This time is well spent as good planning and scheduling is a requirement for a successful project. The schedule, together with a reporting scheme, ensures that the project is progressing as expected or quickly informs management if it isn't. The schedule provides a primary communication channel between the technical and managerial personnel. The schedule must, therefore, be correct and meaningful to both the technical and managerial teams. The monitoring of project progress when compared to the schedule informs management of the project status. If problems develop, management can be quickly informed so that corrective action can be initiated. The plan and schedule provides a specific guideline for the technical personnel to assist in visualizing the relationship of specific tasks to the total project.

To accomplish effective software planning, a set of three schedules must be generated. These schedules are an activity network of tasks, a Gantt chart of personnel resources utilization and a table of computer resource utilization. The project planning and scheduling is accomplished in the following steps:

Define and estimate tasks

Generate task activity network and schedule

Generate personnel and computer resources schedules

Update activity network with resource utilization data

Verify the interactions of the three schedules.

Many projects have had a good plan and schedule of tasks to be accomplished and have failed to be completed on time. One of the causes of this failure is the lack of a resources utilization schedule which is interactive with the task schedule. The limited personnel and computer resources must be carefully accounted for in the overall project plan. The planning and scheduling method must, therefore, account for the characteristics of software development and the interaction of limited resources upon the task schedule.

The plan must also be flexible to accommodate schedule adjustments during the project caused by inaccurate estimates or unexpected events.

The planning of a software development project begins with defining the tasks to be accomplished. Then estimates of the resources for each task are made. Finally the interdependencies of the tasks must be described. The scheduling of the project can then be accomplished. The schedule must account for the tasks and utilization of the resources. As the project progresses, the plan and schedule must be modified if necessary to reflect the project status and any new developments.

TASK DEFINITION

Based on the functional and design requirements of the system, the software design can be established. Using a "Top Down Technique," the software is decomposed into hierarchical tasks each of which can be clearly defined. The decomposition process consists of subdividing each task into the next level of detail. Each task at the lowest level of detail consists of specific actions such as design, code, debug/test or integrate for each distinct program entity. The level of decomposition is of course variable, dependent upon the overall project. This level must be

detailed enough to provide a capability of timely monitoring. If the task breakdown is at too high a level, the project could be significantly behind schedule before management is informed. If the level of decomposition is too low, the planning, scheduling and tracking of progress becomes an unmanageable task because of the excessive paper work. Basically, the level of decomposition should provide visibility in the time frame of the schedule for progress reporting to management. For example, if management should be made aware of progress on a bi-weekly basis, then specific tasks should have a duration of from one to four weeks. This level of decomposition should not be a burden of record keeping and should be adequate for management to see and react to problems so that corrective action can be taken in a timely fashion. In a large project with several levels of management, different schedules oriented toward each hierarchical level of tasks may be required.

During the planning stage, all tasks must be anticipated because errors of omission can be at least as costly as errors of commission. It becomes very difficult and costly to have to add unplanned-for tasks after the project has progressed downstream. A careful top-down analysis of the problem should define all necessary tasks at the beginning. Extra attention must be given to tasks and programs which are required to support the main effort. These secondary tasks are frequently omitted from the original plans for projects, but they must however be performed, and will require both personnel and computer resources. Because of the dependence of main programs on the support programs, support programs must be completed prior to the main programs. Therefore, accounting for the support programs at the first stages of design is very important.

ESTIMATING

Each of the tasks should be identified and clearly defined so that a valid estimate of the required personnel and computer resources can be made. With inaccurate estimates, rescheduling will be done frequently as the project continues until valid estimates are made. This activity prevents management from clearly seeing what is happening and from making rational decisions. Estimates are not perfect, but they must be reasonably good for a plan and schedule to be effective. Methods of estimating software are quite varied. Estimating methods range from the use of accurate records on previous projects to uneducated guesses. Specific techniques for estimating are beyond the scope of this paper, but it is assumed that the estimates are derived from the best available technique.

The estimating should be made in a bottom-up fashion. The lowest level tasks are estimated first because they have the most specifically defined details. These estimates are then summed to provide the estimates for higher level tasks and the total project. The bottom-up estimate should be verified by comparison with another estimate such as a top-down estimate. A top-down estimate is generated by evaluating the total project effort in size and complexity by comparison with previous projects. Each specific task should be estimated in person days or weeks and computer resources in hours required per week. The personnel resources estimate must include the number and type of personnel required and account for training or familiarization time needed. The task estimate will indicate the time required for each person and the total task duration. The computer resources estimate must include CPU time, terminal use time and any other significant resources.

Once these estimates are made, they should not be modified unless the modification can be justified by new data affecting the estimate. It is assumed that the most reliable method and information available was used in the generation of the estimate. It, therefore, does not make sense to shorten the time required to accomplish a task even if a rescheduling causes it to start late and someone wants it to complete on time. This activity of trimming a valid estimate has led to many panics because a project appears to be on schedule until the end and suddenly is far behind. However, if new valid information affects the estimate and the change is justified, it should certainly be made. Deliberately ignoring valuable information which causes a change to original estimates seldom leads to success. For a plan and schedule to be a useful tool, it must be maintained as accurately as possible.

NETWORKING

Programming is an activity oriented process, consisting of activities such as design, code, debug/test, and integration. There is not necessarily a unique event occurring at the termination of each activity. Thus, it is more appropriate to consider the activities than the events such as completion of documents. The task schedule must, therefore, be an activity oriented schedule.

Another important characteristic of software development is the interdependency of the activities. The tasks for each module must be performed in a designated sequence and one task cannot be started until another is completed. The various design levels, coding, test/debug, and system integration tasks must be accomplished in a chronological sequence. There is also an inter-module dependency. Because of the top-down design and testing technique, certain modules must be completed and integrated before others can be integrated into the system. This characteristic or interdependency requires that the scheduling technique must be a network type so that the interdependencies of the tasks and the effects of one event on successive tasks and the overall project can be visualized.

The critical path method (CPM) is ideally suited for software planning and scheduling. CPM is an activity oriented network technique. This enables CPM to show the interdependencies of the software tasks. CPM provides the calculation of float times in the paths and determination of the critical path, the one with zero float time. This capability provides management with the rapid view of the critical tasks which must be monitored more closely.

After all the tasks have been defined, the next step is to lay out the complete network of tasks based on the interdependencies using CPM. This network plan must also indicate the effects of tasks external to the software. The availability of hardware or software from other activities must be indicated. Similarly, if a software task affects other activities, it should be indicated on the network. This helps to ensure that proper communication between major activities of a project is maintained. If changes must be made to a project's schedule, the effects of this on other activities of the project must be considered and the manager of those activities informed. Figure 1 presents a sample of a software network.

The generation of a network chart should be clearly labeled, easy to read and follow basic guidelines presented by O'Brien[6] to ensure its usability. If it fails to conform to these guidelines, it will be quickly discarded as useless.

RESOURCES UTILIZATION

Another characteristic of a software project which complicates the schedule and control activities is the interactions of the finite resources with the task schedule. The two primary resources are the personnel and computer time. The failure to realize the interactions of finite resources with the task schedule has led to severe difficulties in many projects.

Because of the nature of software development, personnel cannot be randomly reassigned to tasks on the schedule. There is a training and familiarization time required to accomplish the task correctly if a new person is assigned to a new task. It is also often more difficult for several individuals to perform the same function on the same task simultaneously. Because of the intercommunication requirements, three people cannot accomplish a task in one-third of the time required for one person. Another effect of limited personnel is that when one programmer is delayed on a task, the successive tasks for which he has been scheduled will be delayed, possibly affecting the overall project schedule. This effect is not directly visible from the schedule of tasks only.

The computer time resource can seriously affect a project schedule. If the computer becomes overburdened, the turnaround time is adversely affected which can lead to delays in task completions. All of the computer resources must be accounted for in the scheduling including terminals and keypunching facilities because any inadequate resources can produce a delay. In systems such as simulators, in addition to program development,

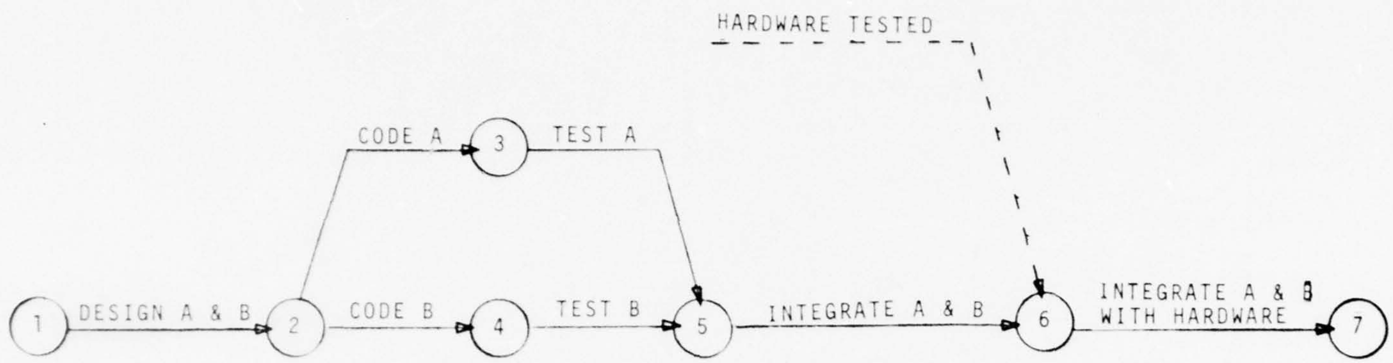

Figure 1. Software Network

the computer test-bed time to integrate the software and hardware is extremely important in scheduling. Projects have reached the final stages before it was discovered that 48 hours of computer time was required per day to complete the project as scheduled. This led to serious delays from which there was no possible recovery. It is, therefore, necessary to ensure that the task schedule does not cause an overrun of the available computer resources. Thus, the scheduling technique must initially account for the utilization of resources and their interactions with the tasks.

SCHEDULING

Having networked the tasks, we are ready to generate the schedules for the project. The task time estimates are added to the network and the path times are computed. These estimating times should be in whole units of days or weeks as smaller units are not significant for large software projects. The estimated task duration times are used to compute start and end times for each task, and from that, the float times of each one. The path with zero float time is the critical path and the length of this path is the minimum time to complete the project. The critical path is compared with the required completion time of the project. If a conflict exists with the time required being greater than allowed, it must be resolved at this time. Either the project completion time must be increased or the network plan must be modified. After this conflict is resolved, the resources schedules can be generated. The personnel resources schedule consists of a series of Gantt charts or a table of times indicating each person, their assigned tasks, and the times during which they are working on these tasks. This information can then be fed back into the network to schedule the tasks and float times on the noncritical paths. The utilization of specific personnel for selected tasks may affect the overall task schedule. Indications of this effect should be entered on the network in the form of dashed lines with appropriate labels indicating that certain tasks cannot begin until the personnel have completed other tasks and are available. This additional information may aid in the quick assessment of the effects of possible changes to the schedule. The effects of personnel scheduling may even change the critical path of the project.

This phase of the process may reveal that more personnel are required during certain periods or that some personnel have periods with no designated tasks. If it is found that these schedules are incompatible, then adjustments must be made either in the task personnel assignments or the task network. Several iterations of adjustments to the network and personnel schedules may be required to obtain the desired schedules. Figure 2 presents a sample personnel schedule.

Once the task and personnel schedules have been satisfied, the computer resources schedule can be generated. This operation can be performed simultaneously with the personnel schedule, but it becomes more complicated if done manually. This schedule will indicate computer resource requirements by task on a weekly basis. This schedule must account for the type of system to be used. For example, if on-line terminals are to be used, the terminal usage times must be evaluated in addition to total computer time. Based on these inputs, the total computer resources can be computed for each week. This schedule can then be evaluated to determine if there are sufficient terminals available, or how many shifts the computer must be run and if there is sufficient computer power available. If the schedule shows a requirement for more than 168 hours of computer usage per week for the last few weeks, then either a second computer is required or the schedule requires adjustment. Failure to plan for computer resources has been the downfall of many projects. Suddenly at the end of the project, everyone wants computer time and there isn't sufficient time available. The project which was on schedule is suddenly delayed significantly just before completion. This tragic happening can be avoided through proper planning of resources at the beginning of the project. Figure 3 presents a sample computer resources schedule.

This scheduling process can be automated by using a computer program. The program can compute the critical path and verify that the resources are utilized effectively. The task assignment and network plan must, however, be performed manually because of the subjective nature of the decisions. The program cannot know task interrelationships and which person can effectively perform which tasks; and random task assignment is not advised

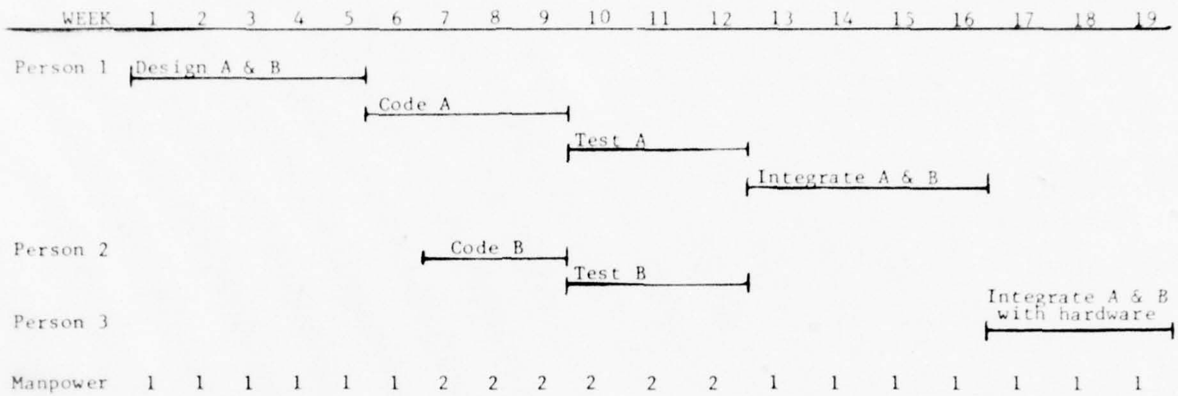

Figure 2. Personnel Resources Schedule

WEEK	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Design A & B														
Code A	5	10	15	5										
Code B		5	5	10										
Test A					5	10	10							
Test B					5	5	10							
Integrate A & B								5	10	15	15			
Integrate A & B with hardware												10	10	10
Total Time	5	15	20	15	10	15	20	5	10	15	15	10	10	10

Figure 3. Computer Resources Schedule

because all personnel are not equal in ability and experience.

The network schedule can be easily oriented toward calendar time. This revised schedule can account for vacation, holiday, and weekend times and provide task completion calendar dates. After the initial schedule has been generated, the calendar start date and time off days can be factored in resulting in a calendar oriented schedule such as in Figure 4. This information can be entered into the network chart resulting in a chart as presented in Figure 5.

On a large project, there may be several levels of managers for the software project. These individuals have different levels of interest in the progress of the project. Therefore, different levels of the task network can be generated corresponding to the top-down hierarchy of tasks. This capability provides each manager with a reasonable schedule for monitoring project progress without unnecessary details, applicable only to the lower level manager.

PROGRESS MONITORING

Once the task network and resources schedules have been completed, they can be used to monitor the progress of the project. It is important to remember that the plan and schedules are based on estimates. The schedule serves as a guide but is not perfect. As the project proceeds, changes may be required in the schedule and plan. Therefore, they must be flexible, and it must be possible to implement changes. Very small deviations may be ignored because the effort involved in documenting the schedule change is significant. A task which deviates from schedule by one week out of 10 or 20 should not cause a schedule update as the estimate may be off by 5 or 10% which could nullify the deviation. Of course, the decision to regenerate the schedule is subjective and no hard and fast rule can be made. Major changes affecting schedule must lead to a reschedule process. If the changes affect the resource estimates, new estimates must be generated and used to update schedules. The task network, personnel and computer resources schedules must all be updated and verified for compatibility. The schedules can then be used by management to track the project progress. When significant deviations occur, management can quickly react to accommodate the changes. As long as no significant schedule deviations exist, management can devote its energies to other projects which require assistance. This management-by-exception is highly dependent upon the belief that the schedule is accurate and that the reporting of progress is true.

Progress reporting should be highly objective and not subjective. Although the project is activity oriented, each activity must be clearly defined so that it can be easily seen when it begins and ends. This is essential so that progress reports do not indicate 90% completion for 50% of the time. The person reporting the status must be able to produce visible evidence of task completion such as a listing or document which can be easily evaluated. The lowest level tasks are considered to be zero percent complete until they are 100% completed. This policy avoids subjective and often meaningless status reports. The short duration of these tasks accomplished through the heirarchical decomposition makes this method of status reporting possible.

Accurate records of the progress and exact resource expenditures should be maintained. The data collection of actual personnel and computer resource expenditures can be part of the progress monitoring activity. If a rescheduling occurs, the old schedule should be filed and not discarded. When the project is complete, this data base can then be used for evaluating the overall project accomplishments and for future estimating and planning activities. Whether the project follows the original schedule or not, the collection of this data is very useful for future reference.

CONCLUSION

A large software project is a very complex task. The problems of managing such a project can be greatly reduced through proper planning and scheduling of the tasks, personnel and computer resources. One of the keys to successful scheduling is to consider all of these items simultaneously to account for their interactions, and the interdependencies of the various software tasks. Using a network for task planning and scheduling, Gantt charts for personnel resources and a table of computer resources

			RELATIVE DATES							CALENDAR DATES	
ACTIVITY	DURATION	TASK DESCRIPTION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	POSSIBLE FLOAT	SCHEDULED START	SCHEDULED FINISH	SCHEDULED START	SCHEDULED FINISH
1-2	5	Design A&B	0	5	0	5	0	0	5	1-10-77	2-14-77
2-3	4	Code A	5	9	5	9	0	5	9	2-14-77	3-14-77
2-4	3	Code B	5	8	6	9	1	6	9	2-21-77	3-14-77
3-5	3	Test A	9	12	9	12	0	9	12	3-14-77	4-4-77
4-5	3	Test B	8	11	9	12	1	9	12	3-14-77	4-4-77
5-6	4	Integrate A & B	12	16	12	16	0	12	16	4-4-77	5-2-77
6-7	3	Integrate A & B with hardware	16	19	16	19	0	16	19	5-2-77	5-23-77

Figure 4. Calendar Schedule

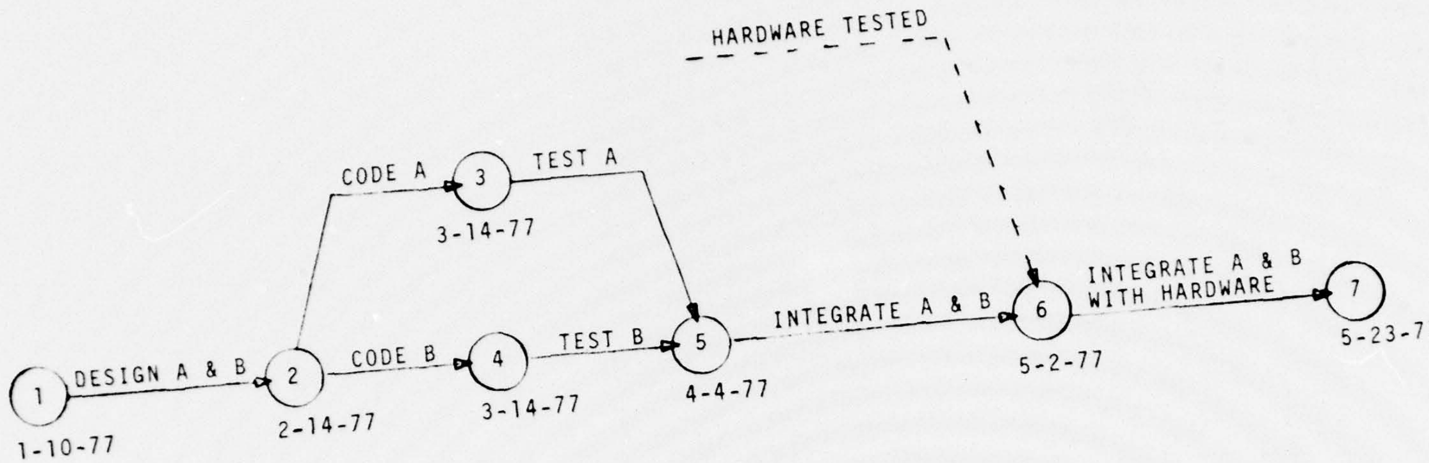

Figure 5. Software Network With Dates

utilization, the problem can be handled in an effective manner.

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THE EFFICIENCY OF FORTRAN IN SIMULATION COMPUTERS

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INTRODUCTION

The task of initially selecting and sizing computer systems for training simulators is becoming more difficult. Current Air Force and Navy simulator specifications state that the software shall be programmed in FORTRAN to the maximum degree technically feasible. Although the use of a higher level language such as FORTRAN is desirable in many respects for both simulator user and contractor, it entails an extensive new effort for the contractor during computer selection and sizing. Previously, software for simulators was programmed in assembly language. A thorough understanding of the adverse impact of FORTRAN on computer loading is necessary to reduce the risk involved with computer selection.

COMPUTER SELECTION CONSIDERATIONS

The various types of computers and the size of their associated operational programs for a number of Air Force simulators are shown in Table 1 which was extracted from Reference 1. Twelve different types of computers are used in the twenty-one simulators identified. From one to four computers are used per simulator. The size of these computer systems as indicated by words of core in the table varies from 30K to 194K (where K=1000). In summary, there is a wide variation in the type and size of computer systems used in simulators.

Selection of a computer system must include an assessment of performance as well as factors such as cost, reliability, maintainability, configuration control, data and availability of equipment. A discussion of computer performance follows.

To select a computer system for a simulator application, the processing requirements must be determined from the amount and fidelity of the simulation required. All data transfers must be analyzed to determine the proper type and speed for each interface. Simulator computers are typically compute limited, not input/output limited.

In the past when simulator software was programmed in assembly language, a computer loading estimate was developed using the instruction set of the candidate computer. This estimate determined the approximate number of computer memory words required and was subdivided into instructions and data. From the estimated number of instructions and instruction execution times, the time required to perform all computations and input/output was estimated. The computer system was then sized as far as memory and central processing units are concerned. For present simulator procurements, this method is no longer adequate because it does not consider the effect of FORTRAN on the computer loading estimate. This paper will discuss and measure several aspects of that effect.

For a real-time application, it is necessary to determine whether the computer system being considered is sufficiently fast to perform all computations and input/output and whether the resultant computer loading is within the real-time constraint of the system. For digital flight simulators, the real-time constraint is a stringent one where solution rates of up to 60 times per second may be required.

Resolution and accuracy requirements also are considered before a computer system is selected. These requirements are analyzed for both computations and input/output operations to determine if the word length of the considered computer is adequate.

Optional features of the considered computer also must be evaluated, such as additional hardware interrupts or other processor options. Throughout a computer system analysis, the cost and cost effectiveness of various components and features are considered.

TABLE 1. COMPUTATION SYSTEMS COMPENDIUM*

TRAINING DEVICE	COMPUTER	COMPUTERS/ SIMULATOR	LENGTH OF THE OPERATIONAL COMPUTER PROGRAM SYSTEM (WORDS OF CORE)
C-135B	MARK I	1	NOT AVAILABLE
C-141A	CDC 921	2	38K
C-141A	SEL 840A	1	34K
F-4E	GP4B (SINGER)	1	92K
C-5A	SEL 840A/840MP	2	63K
F-111A	GP4	1	92K
FB-111A (BOMB/NAV)	SIGMA 5	2	88K
FB-111A	SIGMA 5	3	180K
A-7D	DC 6024/1	1	40K
HH-53C	DC 6024/3	1	30K
CH-3	DC 6024/3	1	30K
F-111D	GP4B	2	194K
F-111F	GP4B	2	175K
F-15	DC 6024/4	2	103K
T-37	DC 6024/4	3/4 COCKPITS	42K
T-38	DC 6024/4	3/4 COCKPITS	49K
B-52 (MOD)	DC 6024/5	1	30K
SEWT (SIMULATOR FOR ELECTRONIC WARFARE)	SEL 86	1	50K
ASUPT (ADVANCED SIMULATOR FOR UNDER-GRADUATE PILOT TRAINING)	SEL 86	3	FLIGHT 83K VISUAL 32K (FORTRAN)
SAAC (SIMULATOR FOR AIR-TO-AIR COMBAT)	SIGMA 5	4	80-100K (FORTRAN)
UNTS (UNDERGRADUATE NAVIGATION TRAINING SIMULATOR)	HONEYWELL H 716	41/52 STATIONS	COMPLEX 51K 13 EA RADAR CONTROL 9K (1 TIME)

*THE DATA IN THIS TABLE WAS EXTRACTED FROM AIR FORCE MASTER PLAN SIMULATORS FOR AIRCREW TRAINING. FINAL REPORT, DECEMBER 1975

Since a real-time system often must be changed to meet additional requirements, system expansion capabilities are analyzed. The system should be capable of expanding in a modular manner with virtually no disturbance to current operations.

SIGNIFICANT COMPUTER PERFORMANCE CHARACTERISTICS

For simulators currently being specified, performance characteristics of greatest significance are:

Speed

FORTRAN efficiency

Multiprocessor capability

Increased addressing capability

Speed, in terms of IPS (instructions per second), has always been and continues to be of primary importance in simulator computer selection. FORTRAN efficiency, which is the subject of this paper, has become a critical item because of the requirement to use FORTRAN as the primary programming language. Multiprocessor capability and direct addressing of increasingly larger blocks of memory have become significant items because of increasing simulation requirements and computer spare time and memory requirements of up to 40%.

FORTRAN VS. ASSEMBLY LANGUAGE EFFICIENCY

A study was formulated in order to evaluate the various coding types that exist in a simulator and determine which types could be efficiently programmed in FORTRAN. Simulation programs written in Harris SLASH 4 assembly language from the F-15 Flight Simulator developed by Goodyear Aerospace were used as the input for this study.

A computer program was developed to read Harris assembly language source code, classify the code into various types and print the code type distribution data.

This data was examined to determine which coding types should be studied in detail. The criteria for selection included a significant amount of use in several programs and a type which could be isolated for study. The selected coding types were then evaluated for the effects of the FORTRAN compiler on the size and running time of the code. The areas selected for study were bit manipulations, logical operations, floating point arithmetic and basic instructions. These types of processing were studied by comparing abbreviated FORTRAN and assembly versions of F-15 simulator programs.

The Harris FORTRAN compiler had as an optional feature an optimizer which processed the FORTRAN output and produced more efficient code in several areas. Quantitative results of optimized FORTRAN vs assembly language efficiency for the various processing types are shown in Table 2. A discussion of each type of processing follows.

BIT OPERATIONS

Bit operations are defined as those which manipulate a single bit either via a register or directly in memory. It was theorized that these would provide severe difficulty for FORTRAN to handle efficiently because there is no direct reference to individual bits in FORTRAN. The HUD control (HUDCTL) program was selected for the test. Portions of HUDCTL were extracted and coded in FORTRAN and assembly language. These portions were considered to be representative of simulator bit processing. There were two FORTRAN versions generated. One version used a larger data matrix with one word representing each possible discrete signal.

Four runs were made through different paths of the program logic. This was done to ensure that several code variations were exercised for a larger data sample. The results in Table 2 were based on the average execution time for these four runs. It was concluded that, for the Harris SLASH 4, FORTRAN cannot efficiently handle bit manipulations. This computer is designed to efficiently manipulate single bits and is more efficient than some other computers in this respect. However, the FORTRAN compiler is not designed for bit manipulation and, therefore, does not take advantage of the machine capability. Nor does the optimizer significantly improve the results for this type of processing. The use of one word per signal instead of a packed format improved the program time and core efficiency but required a much larger core area for the data. In this example, it was assumed that the 20 data words were fully packed with 24 discretes

TABLE 2. OPTIMIZED FORTRAN VS ASSEMBLY LANGUAGE EFFICIENCY, HARRIS FORTRAN

TYPE OF PROCESSING	SIZE OF ASSEMBLY SAMPLE (WORDS)	% SIZE EXPANSION OVER ASSEMBLY LANGUAGE	% TIME EXPANSION OVER ASSEMBLY LANGUAGE
BIT (PACKED DATA)	97	186	185
BIT (UNPACKED DATA)	51	41	33
BASIC (TRANSFER, ADD, SUBTRACT, COMPARE, BRANCH)	178	11	10
FLOATING POINT	445	12	14
LOGICAL	106	5	7
AVERAGE OF ABOVE (EXCLUSIVE OF BIT, PACKED DATA)	-	17	16

in each. The word version, therefore, required 480 words for data instead of 20. This method, though much better than the packed format method, is still not efficient enough for a bit manipulating program. An alternative to the use of FORTRAN would be to code programs with a large amount of bit manipulation instructions in assembly language or to use in-line assembly language code for this type of processing. If this is not possible, and timing is a critical factor, the use of one signal per word is another possible alternative if sufficient core is available.

No FORTRAN compilers of the candidate computers for simulators have the capability to handle individual bits efficiently. Some of these computers also lack the capability to handle bits efficiently even in assembly language because of different machine architecture. For these computers, the difference between assembly language and FORTRAN may not be as great.

LOGICAL OPERATIONS

Logical operations are defined as the AND, OR and XOR functions. It was theorized that the Harris SLASH 4 FORTRAN could efficiently handle a program of this type which masks and manipulates several bits at one time. The Built-In-Test (BIT) program was selected as representative of significant use of this kind of code. Selected portions of BIT were coded both in FORTRAN and assembly language.

Six runs were made to exercise various program paths and ensure that coding was identical in both the assembly and FORTRAN versions. The results indicate that with optimization, FORTRAN is almost as efficient as assembly language. This indicates that programs with logical operations could be coded in FORTRAN for the Harris SLASH 4 computer. Some other computer systems, however, do not have the AND, OR, and XOR operators available for masking operations except as intrinsic functions. If these compilers are used, and generate function calls instead of simple instructions, the efficiency will be greatly reduced. For these systems, their standard FORTRAN may be adequate for logic functions. If these compilers generate direct code as efficiently as the Harris compiler instead of function calls, they would be adequate.

FLOATING POINT

Floating point arithmetic operations comprise a major portion of simulator programs and, thus, it is important that FORTRAN efficiently compile it. The Forces and Moments (FCMOM) program has many floating point equations and had previously been compiled by the Harris optimizing compiler. The generated code was studied for its efficiency. It was found to be very efficient, as expected. There is no problem in using FORTRAN for floating point equations. Since FCMOM is 90% floating point operations, it is a good benchmark for assessing FORTRAN floating point efficiency. The FCMOM program will be discussed in more detail in the benchmark section of this paper.

BASIC INSTRUCTIONS

The category of basic instructions includes integer arithmetic, transfers, compares, branches. A benchmark containing these instruction types was generated from the Tactics Data Save (TACSAV) program. It was anticipated the FORTRAN optimizing compiler would handle these types of instructions very efficiently. The benchmark results, presented in Table 2 indicate this is true. Programs composed primarily of these basic instructions could, therefore, be efficiently programmed in FORTRAN.

OTHER INSTRUCTION TYPES

Shift instructions were found to be a small percentage of F-15 simulator instructions and, therefore, considered to be insignificant. The Harris compiler has special instructions (SHIFT and ROTAT) which enable efficient shift operations. Other compilers rely on the optimizer to translate a power of 2 into a shift operation. This also provides efficient coding except in the case when end around shifting is desired. This operation, though not handled directly by many compilers, is not critical to simulator programs. Thus, there appears to be no problem with most shift instructions being handled by FORTRAN.

Byte instructions were also found to be a small percentage of F-15 simulator instructions. Since these instructions really are designed to handle the lower 8 bits of a word in the accumulator, it appears that there

will be no significant change in efficiency in using FORTRAN for programs which contain these instructions.

Input/output and interrupt handling functions are very ill-suited to FORTRAN. It is, therefore, necessary that routines with these instructions be written in assembly language or in FORTRAN with some in-line assembly code in special areas. FORTRAN, unlike assembly language, does not provide a direct input/output capability. The calling of general-purpose I/O subroutines by FORTRAN in lieu of direct input/output is unacceptable because of their inherent inefficiency. There is no capability in FORTRAN to save registers as is required for an interrupt routine. Therefore, simulator programs which contain I/O functions or which are interrupt initiated cannot be coded in FORTRAN.

FORTRAN VS. ASSEMBLY LANGUAGE EFFICIENCY - CONCLUSIONS

The operations of programs were divided into coding types, and these types were evaluated for their use in FORTRAN. The following types were found to be inadequate for FORTRAN: single bit manipulation, input/output, and interrupt processing. The processing types which are amenable to FORTRAN are floating point arithmetic, logical functions, and basic instructions which include transfers, integer arithmetic, branches, compares, shifts and byte operations.

OPTIMIZATION CONSIDERATIONS

As mentioned earlier, the Harris FORTRAN compiler features an optimizer which processes the FORTRAN output and produces more efficient object code in several areas. This optimization is all local; that is, each statement is optimized independently of other statements. The result of this optimization is a reduction in module storage and execution time requirements. The actual reductions are dependent upon the amount of code in those areas that the optimizer operates on. According to Reference 2, for a typical module the number of memory words required to store the program exclusive of data words is reduced by 10 to 50%. The computation time exclusive of input/output time is reduced by 10 to 30%. This is corroborated by the actual results for the types of processing discussed above. These results in terms of percent expansion before and after optimization, are shown in Table 3. The average core savings exclusive of data for all five processing types in the Table was 43%. The average execution time savings was 29%. These savings are significant enough to demonstrate the importance of using an optimizing FORTRAN compiler in real-time training simulators.

Therefore, any computer selected for use in a training simulator which will be programmed in FORTRAN should have an optimizing compiler. The Harris optimizer is efficient enough to make the use of FORTRAN possible in simulators. The optimizer does not enable the efficient use of bit manipulation, I/O and interrupts. These instruction types would have to be coded in assembly language to maintain high program efficiency. Other computers which could be selected for simulation must have a FORTRAN optimizer at least as efficient as the Harris optimizer. Some of these systems have global optimizers, which optimize code across more than one statement at a time, thus providing increased efficiency.

A comparison of two optimizing compilers that are designed for execution on the same computer, the Interdata 8/32, is shown in Table 4. FORTRAN VI, which is a superset of the ANSI Standard (X3.9-1966), performs optimizations which include subscript evaluation by linearization, common index elimination, register allocation and transfer logic. FORTRAN VII which is being implemented according to one of the latest ANSI Standards (X3J3/56), performs more extensive optimizations including both machine independent and machine dependent optimizations. Table 4 shows results for the combined totals of the FCMOM and ELECT benchmark programs which are discussed in the following section of this paper. The FORTRAN VII compiler was not available for an actual benchmark run because the compiler was undergoing final acceptance test. However, projected results were obtained by hand-optimizing the code generated by the FORTRAN VI compiler according to the design specification of the FORTRAN VII compiler. From the table, it can be seen that a 32% savings in memory and a 23% savings in time are achieved with the compiler with more extensive optimization.

TABLE 3. BEFORE AND AFTER OPTIMIZATION, HARRIS FORTRAN

TYPE OF PROCESSING	% SIZE EXPANSION OVER ASSEMBLY LANGUAGE		% TIME EXPANSION OVER ASSEMBLY LANGUAGE	
	BEFORE	AFTER	BEFORE	AFTER
BIT (PACKED DATA)	208	186	189	185
BIT (UNPACKED DATA)	90	41	48	33
LOGICAL	31	5	24	7
FLOATING POINT	22	12	25	14
BASIC	93	11	62	10
	AVERAGE CORE SAVINGS (OPTIMIZED VS NON-OPTIMIZED)		AVERAGE TIME SAVINGS (OPTIMIZED VS NON-OPTIMIZED)	
	43%		29%	

TABLE 4. A COMPARISON OF TWO OPTIMIZING COMPILERS

COMBINED TOTALS OF FCMOM AND ELECT BENCHMARKS	INTERDATA 8/32	
	FORTRAN VI	FORTRAN VII*
MEMORY TOTAL (WORDS)	1277	867
% MEMORY SAVINGS	-	32
TIME TOTAL (MSEC)	1620	1250
% TIME SAVINGS	-	23

*PROJECTED RESULTS

BENCHMARK PROGRAMS

Two FORTRAN benchmark programs were used to measure the relative performance capabilities of potential simulation computers and their FORTRAN compilers. The benchmark programs were run on each computer. These programs are representative samples of the kinds of programs that are used in flight simulators. Two performance criteria were considered: (1) compiled program size and (2) program execution time. The characteristics of the tested programs on the detailed test results are presented below.

The two programs which were used are FORTRAN versions of assembly language programs selected from the F-15 flight simulator. One program, which is part of the aerodynamics simulation subsystem, evaluates total aircraft forces and moments. The other program simulates one of the aircraft systems, the electrical system.

The Forces and Moments Program (FCMOM) consists almost entirely of arithmetic-type expressions. The number of executable source statements in the FORTRAN program is 83 as compared with 372 in the F-15 assembly language program. Both of these numbers are program size only and as such do not include storage of external variables. The test case that was selected corresponded to an airborne F-15 in a typical flight configuration.

The Electrical Program (ELECT) consists almost entirely of logical expressions. There are 277 executable source statements in the FORTRAN program as compared with 324 in the F-15 assembly language program. Four test cases were selected which correspond to typical operational conditions of the electrical system. An assumption that was made prior to coding the ELECT program was that each discrete input and output resided in a full word. This would have to be done by special I/O hardware or by software which would unpack and pack the discrete inputs and outputs, respectively.

The benchmark programs were run on the following computers:

Harris SLASH 4
Harris SLASH 7
Interdata 8/32
SEL 32/55
MODCOMP IV/25
DEC KL-10
NORSK NORD 50

The results of the test runs on each computer are shown in Table 5.

The size of the FORTRAN Memory Totals in the table is a measure of: (1) compiler efficiency and (2) instruction set power. The first of these two factors is more predominant. The size of the FORTRAN Time Totals in the table provides a measure of computer hardware execution speeds as well as the factors mentioned above.

All of the FORTRAN memory and run time data shown in the tables represent actual benchmark runs except for those marked with an asterisk (*) to designate "projected results."

The SEL 32/55 FCMOM results were generated by substituting specified instruction execution times of the floating point hardware for the times of the firmware instructions actually executed in the benchmark run. The NORD 50 benchmark results were updated from the actual results by factoring in the effect of a pending compiler modification which enables direct, rather than indirect, addressing of FORTRAN common variables. And, as mentioned earlier, the Interdata 8/32 FORTRAN VII results were obtained by hand-optimizing the code generated by the existing FORTRAN VI compiler according to the design specification of the FORTRAN VII compiler.

DISCUSSION OF BENCHMARK RESULTS

The objective of this portion of the paper is not to compare architectures of the seven computers shown in Table 5. However, it is appropriate to classify the computers into three groups: large scale, "midicomputer," and minicomputer. According to Theis[3], a "midicomputer" is a high-performance machine with a mid-length word size and a less than midsize pricetag. Classifying the computers then, the DEC KL-10 with its 36-bit word size is definitely a large-scale computer, the MODCOMP IV/25 with its 16-bit word size is a minicomputer, and the remaining five computers with their 24- and 32-bit word sizes are midicomputers.

As might be expected, the DEC KL-10 provided the best memory/time efficiency using 1% less memory and 40% less execution time than the baseline Harris SLASH 4 assembly language benchmarks. However, associated with

TABLE 5. BENCHMARK RESULTS

	ASSEMBLY	FORTRAN						
COMBINED TOTALS OF FCMOM & ELECT BENCHMARKS	HARRIS SLASH 4	DEC KL-10	HARRIS SLASH 4	HARRIS SLASH 7	INTERDATA 8/32 FORTRAN VII *	SEL 32/55 *	NORSK NORD 50 *	MODCOMP IV/25
MEMORY TOTAL (WORDS)	790	786	940	948	867	816	964	997
% MEMORY CHANGE (FORTRAN VS HARRIS SLASH 4 ASSEMBLY LANGUAGE)		-1	19	20	10	3	22	26
TIME TOTAL (MSEC)	1511	907	1754	1448	1250	1147	1460	2898
% TIME CHANGE (FORTRAN VS HARRIS SLASH 4 ASSEMBLY LANGUAGE)		-40	16	-4	-17	-23	-3	92

*PROJECTED RESULTS

the high performance of this large scale computer is a large scale price tag. The memory efficiency of the five midicomputers ranged from 22% more memory than baseline for the NORD 50 to only 3% more memory than baseline for the SEL 32/55. The execution time efficiency of these computers ranged from 16% more time than baseline for the Harris SLASH 4 to 24% less time than baseline for the SEL 32/55. The MODCOMP IV/25 provided the least efficient results (26% more memory and 92% more time) mainly because it is basically a 16-bit machine with a limited 32-bit capability added on. This results in two 16-bit memory accesses for each 32-bit word and an accompanying increase in execution time.

All of the computers in the table made use of optimizing compilers in the benchmark runs.

SUMMARY

A summary of the results of the limited analysis of FORTRAN efficiency performed for this paper are presented below:

- An average memory penalty of 17% and time penalty of 16% was incurred for four types of processing (Table 2) in a Harris FORTRAN vs assembly language efficiency comparison. This was further confirmed by the combined benchmark totals for the Harris SLASH 4 (Table 5) where the memory penalty was 19% and the time penalty was 16%. According to Trainor and Burlakoff[4], these results are consistent with published results for other comparable HOLS that have indicated a 10% to 20% penalty.
- An average memory savings of 43% and time savings of 29% (Table 3) was achieved in an optimizing vs. non-optimizing FORTRAN compiler comparison.
- A memory savings of 32% and time savings of 23% was achieved in a comparison of two optimizing compilers.
- Benchmark results for seven candidate simulation computers were presented exhibiting a wide range of memory and execution time efficiencies.

CONCLUSIONS

FORTRAN efficiency is an important factor in evaluating the performance of computers for training simulators. From the results of the analysis of FORTRAN efficiency summarized above, the conclusions are as follows:

- Minimal execution time and memory penalties are incurred for most types of processing which are performed in training simulators.
- An optimizing compiler is essential.
- An optimizing compiler that performs extensive optimization is highly desirable.
- A comparison of benchmark results must be performed to assess relative efficiencies of candidate computers.

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IMPACT OF MICROPROCESSORS ON TRAINING DEVICES

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INTRODUCTION

Simulation has long been accepted as a cost-effective training method and is becoming more valuable due to the energy crisis. By simulating operational systems, trainers reduce the use of operational equipment and contribute to fuel savings. Not only do savings result from reduced energy consumption, but also from fewer operational units being required and from a decrease in potential accidents during training.

The computer system in training devices must be capable of performance necessary to meet system requirements. Generally, this will mean a high degree of complexity at both the hardware and software levels. Maintenance and reliability require that the system architecture be the simplest that will meet system performance requirements, yet the complexity of the simulation demands the most mature design within the state-of-the-art.

Early simulators were analog devices. Reprogramming them required extensive circuit modifications and involved considerable expenditures of time and money.

The advent of general-purpose digital computers led to the development of algorithms suitable for modeling both discrete and continuous systems. When these computers became sufficiently fast, real-time digital simulation was a reality. Digital computers were being used in trainers as early as 1962.

The use of digital computers in simulators has resulted in more flexible training devices. Digital computers may require only relatively simple changes in the simulation program to incorporate enhancements in the model. A greater part of modification cost is in the software area. This additional software cost can be somewhat offset by reduced hardware cost. The life of a trainer can also be extended by reprogramming to incorporate various changes in the operational equipment.

Although simulation is a cost-effective training method, the simulators themselves can be expensive. The 2F92 training device cost $16.5 million.(1) Cost constraints now and in the future require that a high degree of effectiveness be obtained at the same or at reduced costs. Devices such as low-cost microprocessors should be considered in the design of training devices.

THE MICROPROCESSOR

Microprocessors are chips that function somewhat like a minicomputer, usually at a slower speed and with a shorter word length. They are, or will become, an important part of common devices in the home and in industry. Point-of-sale terminals, cash registers, television sets, traffic lights, and even pinball machines are currently being controlled by microprocessors. It has been estimated that by 1980 there will be 60 million microprocessors used in microcomputers alone.(2) Microprocessors replace hardwired logic or minicomputers in such applications, but are often used for entirely new purposes.

The microprocessor's rapid growth is due to its great computing power at low cost. Although hardware cost will decrease drastically as microprocessors assume more functions in training devices, the total system cost is likely to remain constant. Software will become even more complex and, therefore, software support will consume a larger part of the total cost.

The use of microprocessors to replace hardwired logic gives the designer the opportunity to make easy production changes. New features can be added in the prototype stage without laying out new circuit boards.

Microprocessor controllers can be applied to most devices and optimized for a particular application. Development time for a microprocessor controlled system can be as little as one-third that of a hardwired system.(3) The actual time depends upon support software available and on the designer's experience with microprocessors. It can be anticipated that most devices requiring logic controls will eventually include one or more microprocessors.

Debugging microprocessor systems presents few problems, being no more difficult and requiring no more time than for hardwired logic systems.(4) The process can be accelerated by simulating the microprocessor on a larger machine and testing the programs prior to implementation.

There are numerous reasons for considering the use of microprocessors in training devices. A few of these are:

a. More powerful simulation systems may result if microprocessors are used as building blocks.

b. Power consumption is low.

c. Systems can be more flexible when microprocessors are incorporated into their design.

d. Overall system reliability is increased by using high-reliability microprocessors and from reducing parts count and decreasing the number of interconnections.

e. The microprocessor is smaller than the circuits it replaces and its use results in smaller equipment.

f. The microprocessor may be used for new applications in the training device. Over 40 percent of the microprocessors now in use are being used for entirely new purposes.

g. The microprocessor may introduce a cost saving when used to replace hardwired circuits.

h. Design time can be decreased resulting in a reduction in cost.

SOFTWARE FOR MICROPROCESSORS

As simulation becomes more realistic, providing better sensory effects, software may become more complex. Microprocessors and other developments in electronics will likely result in better simulation at a lower hardware cost but will place greater demands on software engineering.

A good software system requires thorough analysis prior to design. A systems engineering approach is essential to minimize the cost of the trainer, the initial software cost, and software modification throughout the life of the trainer.

Programming, coding, and assembly of programs require extensive effort. Debugging and verification of programs are time consuming tasks. Program modification at a later date will require extensive effort and special skills. In the past, management has directed its attention toward hardware (and also has placed budget emphasis in this area).

Performance requirements are increasing rapidly, and although software cost is increasing, its rate is not as fast. It has been estimated that computer software costs are three-to-four times as great as computer hardware costs. Forty-to-fifty percent of software cost occurs during hardware-software interaction checkout. Additional demands will be placed on the software staff as microprocessors assume more functions in operational equipment and in simulators.

LANGUAGES FOR PROGRAMMING MICROPROCESSORS

Despite the many advantages quoted for microprocessors, their use requires a thorough knowledge of the relationship between software and hardware. The programming of microprocessors takes considerable effort. Texas Instruments [5] estimates that a small program of less than 2000 instructions can consume 20, to 30 working days if sufficient support software is available. Other estimates [6] range as low as 50 instructions per man-month.

The most direct means, but also the most time consuming programming method, is the use of machine language. At this level, the programmer is closest to the internal operations of the microprocessor and must maintain full knowledge of register usage and memory allocation. Programming of microprocessors, however, can be simplified with any of several languages.

Assembly language, with its mnemonic op-codes, symbolic addresses, and one-to-one correspondence with machine language, makes programming somewhat easier. Assembly language also has advantages over higher level languages. About one-half the code generated by the high-level compilers is produced by an assembler. This results in shorter execution time (for assembled programs) which is especially important in real-time simulation. Trainers, for example, must respond rapidly if they are to reproduce actual system response.

Higher level languages eliminate the need for the programmer to manage register usage or to allocate memory. In addition, structured programs are possible, leading to more reliable programs with fewer opportunities for errors. Documentation is better and enhancements are easily added. A possible disadvantage is that the programmer is further removed from the machine and has less control over memory allocation and register usage. More memory is required and execution time is also increased. Higher level language is presently new and largely unused in the microprocessor field.

Assembly language is commonly used for writing microprocessor programs and

accounts for about 75 percent of the programming in this area.[7] Although resident assemblers are available, cross-assemblers (if a host computer is available) seems to be the usual method for programming microprocessors. Macro-instruction facilities may be desirable and are easily made available on the host computer.

MICROPROCESSORS AND TRAINING DEVICES

The development of training devices utilizing microprocessors as controlling subsystems requires reorientation of priorities and resources. Programs written for microprocessors in control applications consist of a sequence of instructions to implement the desired behavior. Programming these devices requires the skills of a person who is familiar with both hardware and software. A major part of the cost when using microprocessors is in the design of software. In order to obtain the potential benefits offered by microprocessors, additional emphasis must be placed on software engineering and program development.

Medium-scale computers now provide sufficient control for modern training devices. As equipment being simulated become more complex, more powerful simulation will be required if the training device is to provide adequate training. Microprocessors can be key elements in such systems. Providing control and some computing functions at physically separated locations, microprocessors will allow a more complex simulation and provide for improved performance.

An example of current applications of microprocessors in training devices gives an indication of the potential uses of microprocessors in simulation. Hydrosystem's air-traffic-control/radar simulator, interfaced with on-site radar systems, presents both live and simulated radar returns to the trainee. Pseudo-pilots enter commands in response to the audio communications from the trainee and simulated aircraft respond according to parameters stored in read-only-memories. Microprocessors perform block-transfer of data and transformations from rectangular to polar coordinates.

The microprocessor in this training device also stores and updates velocity and climb/dive rates, sums velocity vectors, computes radar slant ranges and target elevation angles.[8] The functions handled by the microprocessors would have previously required a minicomputer.

CONCLUSIONS

Numerous innovative applications of the microprocessor are an indication of its versatility. Uses of the microprocessor in training devices include the replacement of hardwired logic and some functions currently being performed by minicomputers.

Although the microprocessor should be considered as a means of reducing hardware costs, other benefits of its use should not be overlooked. Microprocessor programs are easily altered and can extend the life of the training device by facilitating equipment modifications or by providing for enhancements necessary for improved simulation.

With their low cost and large computing power, microprocessors may be used as building blocks throughout the training device. Each of these microprocessors can contribute to the effectiveness of the simulation by providing for data acquisition and data conversion, by performing simulation functions, or in control applications.

Potential applications of the microprocessors in simulators are not limited to replacing existing hardware and minicomputer functions. Because of its availability and flexibility it is likely that entirely new functions for the microprocessor will evolve that will contribute to more effective simulation.

Future applications of microprocessors in training devices are limited by both the imagination of the design engineer and his knowledge of programming techniques. Until engineers acquire the programming skill that can only be obtained through years of programming experience, they must depend upon software experts to assist them in their work with microprocessors.

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BEHAVIORAL VALIDATION OF THE COMPUTER ASSISTED OPERATIONS RESEARCH FACILITY

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INTRODUCTION

The Computer Assisted Operations Research Facility (CAORF) is a highly sophisticated ship maneuvering simulator owned and operated by the National Maritime Research Center. It was designed primarily as a high fidelity simulator to conduct a broad spectrum of applied maritime research. A secondary role has emerged for CAORF for the specialized training of VLCC masters in ports such as Valdez, Alaska. The cost of CAORF training for Valdez, in terms of resource conservation and other factors, has been demonstrated to be much less than the cost of comparable at-sea training. Recent interest by the maritime industry for the increased use of simulator training will require prototype development; CAORF is the ideal facility for this type of maritime training research. Hence, multiple roles have emerged for this facility: 1) to conduct research on operational maritime problems; and, 2) to develop maritime training programs and identify training device characteristics. Both of these roles exemplify aspects of the goal of resource conservation through simulation. The effectiveness of achieving this goal is addressed in this paper in terms of CAORF validation, the extent to which mate behavior on CAORF is similar to mate behavior at sea.

CAORF was designed as a research tool to enable the conduct of investigations that would be prohibitive to accomplish at sea. The extensive capabilities designed into CAORF for this purpose also enable its use as an advanced training device. A high fidelity wheelhouse environment is simulated, representing the state-of-the-art in merchant ship bridge simulation (see Figure 1). The major elements of simulation include: 1) the full compliment of ship instrumentation, such as radar and navigation equipment; 2) ship handling characteristics, such as wind effects, turning equations, and tugboat forces; and, 3) a comprehensive visual scene. The computer-generated visual imagery, subtending a 240° horizontal arc and a 24° vertical arc, is the most unique feature of CAORF. The full color visual scene can be constructed of any area and changed in real-time as a function of own ship and other ship actions. The visual scene can vary according to day/night, level of visibility, and color factors. It can include parts of own ship, other ships, coastline, bridges, buildings, oil rigs, and other visual objects.

Of equal importance to the quality of the simulation are the control and performance monitoring capabilities (see Figure 1). These are essential from both a research and training standpoint. The remotely located Control Station provides a complete set of indicators and displays for monitoring the actions of own ship and other ships. These include monitors of the visual scene, geographic plots, radar repeaters, and communication panels. Interrogation and control of all problem parameters may be accomplished from the Control Station. The Human Factors Station compliments the Control Station by providing a variety of remotely controlled audiovisual monitors for observing behavior on the bridge. These two stations permit remote observation and exercise control by a researcher or instructor. Furthermore, interaction with the mate or master on the bridge can be accomplished via CRT displays on the bridge and radio/telephone communication. Extensive computer facilities enable the on-line calculation of performance measures, provide for immediate feedback if desired, and provide for comprehensive post-exercise analysis. These extensive control, performance monitoring, and computational features, although designed for the conduct of research, are excellent training assistance capabilities. They provide the training program developer and instructor with a wide range of

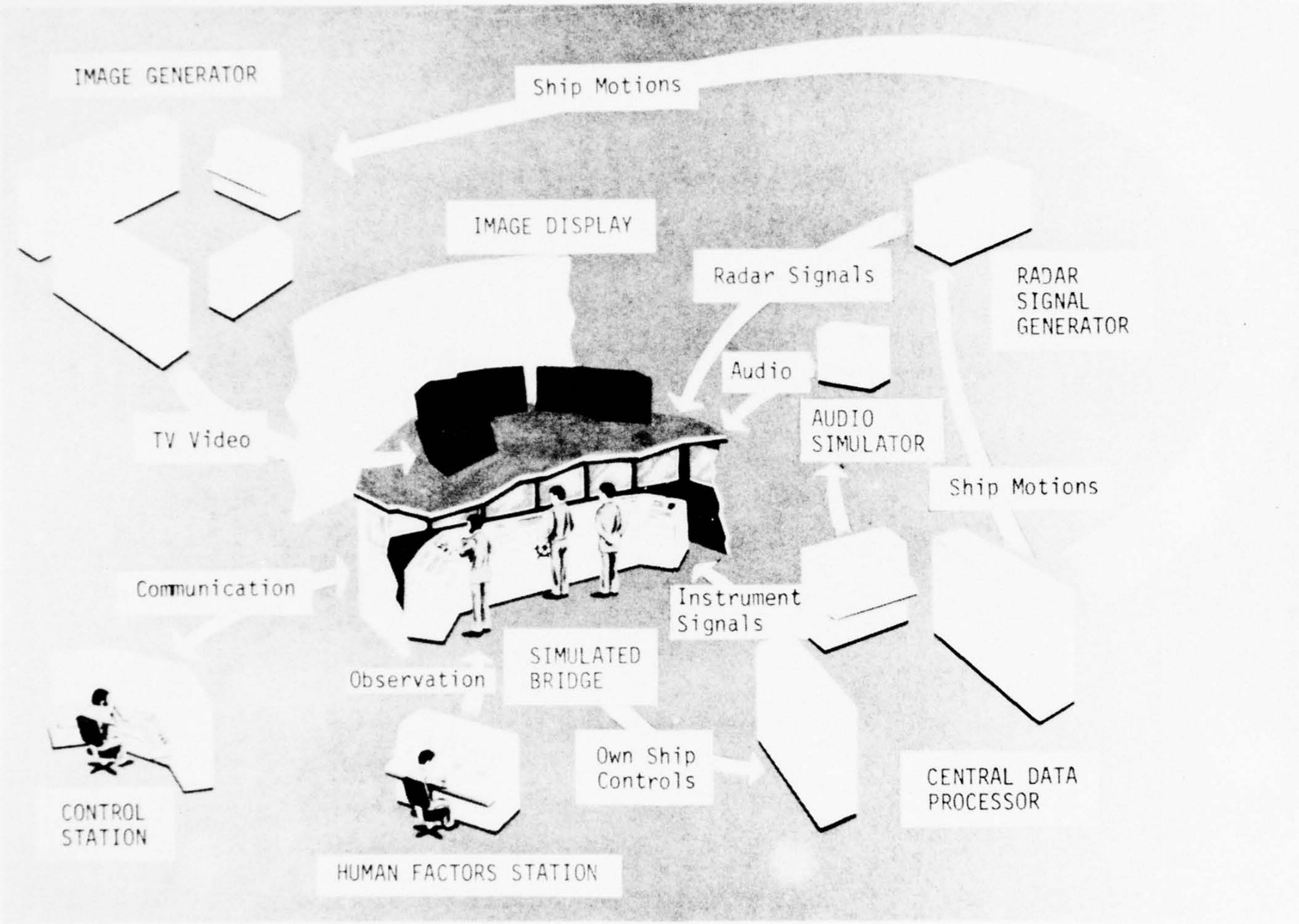

Figure 1. CAORF Subsystems

capabilities with which to develop and implement training.

The effectiveness of a high fidelity simulation facility in the conduct of applied research, or in providing advanced training, is dependent on the validity of elicited behavior. The purpose of incorporating a high degree of fidelity is to assure obtaining behavior on the simulator that is similar to behavior that occurs in the real world environment. Validation of the CAORF simulator was undertaken for this purpose, in essence to ensure that findings on CAORF have a positive relationship to those expected at sea.

The issue of simulator validation may be addressed in three distinct areas:

1. Hardware Validation - e.g., equations of ship motion.
2. Perceptual and Information Processing Validation - the mate's perceptual integration of simulated information (e.g., visual estimation of target range).
3. Behavioral Validation - the mate's behavioral functioning (e.g., the mate's radar-related behavior).

The third area of validation, mate behavior, is addressed by this paper. This area is of fundamental importance in that it may serve as a summary of the first two areas, as well as directly relate to ship performance.

This validation project, which was sponsored by the National Maritime Research Center, was tailored to investigate a variety of validation issues of concern to CAORF. The most important were:

1. The mate's level of activity and radar behavior as a function of situation conditions,
2. Examination of the existence and magnitude of a learning/experience factor when the mate initially reports on the CAORF bridge, and
3. Comparison of research findings between research performed at sea and on CAORF.

BEHAVIORAL VALIDATION APPROACH

Behavioral validation was accomplished by comparing the behavior of mates on CAORF with the behavior of mates in similar situations at sea (see Figure 2). An at-sea data base consisting of mate behavior was compiled from a variety of trips at sea. This computer data base also contains reconstructed target and own ship data for the various at-sea situations. Three four-hour watch scenarios were constructed for use on CAORF from these data. The watches were identical to situations that had occurred at sea near the Cheasapeake Bay, Matanilla Shoals in the Straits of Florida, and the English Channel. The behavior of mates who stood watch on the CAORF bridge during the constructed scenarios (ten mates total) was compared with the mate behavior observed during the similar situations at sea.

The three selected at-sea situations covered a broad range of conditions to provide for the general applicability of the validation results (see Figure 3). A variety of information was developed for each watch based on the at-sea situation: 1) own ship data; 2) target data; 3) environmental conditions; 4) communications guidelines; 5) geographical data; and, 6) ship information and materials. In essence, the mate reported for watch on the CAORF bridge is a duplicate of a watch that had occurred at sea.

The data collection methods employed on CAORF were identical to those used at sea. A trained observer recorded the pertinent information concerning the mate's tasks. A variety of task categories were identified for the at-sea data collection efforts, and also used to classify the tasks observed on CAORF. More than seventy distinct task categories were considered under the following major areas: 1) ship control; 2) navigation; 3) communication; 4) visual; 5) contact assessment; and, 6) logging and miscellaneous.

The validation analysis was conducted in three separate configurations:

1. CAORF Watch Behavior Versus The Identical At-Sea Watch Behavior- The advantage of this approach was that CAORF behavior could be compared with at-sea behavior under identical conditions. The disadvantage was that the behavior of only one mate per at-sea watch could be used for the analysis.
2. CAORF Situation Average Versus Similar At-Sea Situation Average - The three CAORF watches were partitioned into segments on the basis of the situation conditions; average behavioral data were calculated across the

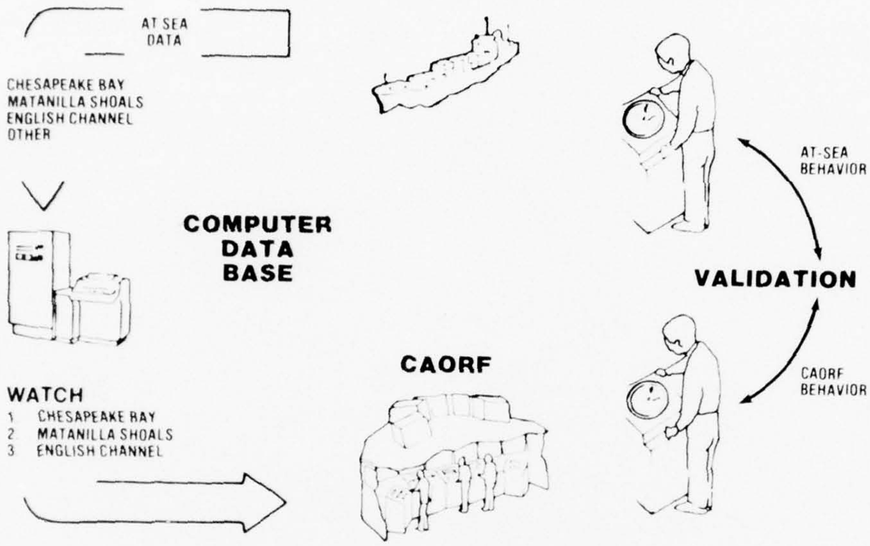

Figure 2. Behavioral Validation Approach

WATCH CONDITIONS				
		WATCH #1	WATCH #2	WATCH #3
LIGHTING	DAY		•	
	NIGHT	•		•
CONTACT LOAD	LOW	•	•	
	MEDIUM	•	•	•
	HIGH			•
NAVIGATION:	OPEN SEA	•	•	•
	COASTAL			
	RESTRICTED			
VISIBILITY:	UNLIMITED	•	•	
	LIMITED 3-7NM			
	LIMITED ≤ 3NM			•
COMMUNICATION:	LOW		•	•
	MEDIUM			
	HIGH	•		
RADAR NOISE:	LOW	•	•	
	HIGH			•
CURRENT SET:	LOW			
	MEDIUM	•	•	
	HIGH			•
NAVIGATION LOAD:	LOW		•	
	MEDIUM	•		
	HIGH			•

Figure 3. Watch Conditions

similar segments. The entire at-sea data base was likewise partitioned into segments, and behavioral averages developed. The advantage of this approach was that the at-sea data for each situation were based on the behavior of several mates.

3. Overall CAORF Average Versus Overall At-Sea Average - This approach developed average data across all CAORF watches, regardless of the situation conditions. The at-sea data were similarly averaged. This approach, although used to compare behavioral data, was primarily used for comparison of CAORF and at-sea ship performance.

The analysis investigated similarities and differences in mate behavior. Behavioral variables that received particular attention were: 1) Task Workload - the percentage of a mate's time that was spent doing particular tasks (e.g., a 20% radar workload means that the mate spent three minutes out of fifteen minutes performing radar tasks); 2) Task Frequency - the number of times in a given period that the mate performed particular tasks; and, 3) Task Duration - the average amount of time the mate spent performing a task. A contact load algorithm was used to provide an objective estimate of the loading placed on the mate by the distribution of ship contacts. The contact load algorithm was developed in an earlier study investigating standardized bridge design (Eclectech Associates, 1976). The contact load parameter is sensitive to the number of contacts (fixed or moving), their range, bearing, speed, and course. This algorithm was particularly useful in partitioning the watches into equivalent segments.

FINDINGS

Mate behavior on CAORF was found to be similar to mate behavior at sea. The level of mate activity, the type of tasks, and the manner in which the tasks were performed were found to change in accordance with the situation conditions, both on CAORF and at sea. A summary of the validation findings is presented in this paper. The interested reader is referred to Hammell (1976) for the complete report.

Overall comparisons between mate behavior on CAORF and at sea are shown in Figure 4. CAORF and at-sea workloads are averaged across all the data for three sets of situation conditions. The data are further broken down according to All Tasks and Radar Tasks categories. A relatively high correlation coefficient was obtained for these data (Spearman Rank Correlation Coefficient: $T = 0.9$, $p < .05$), demonstrating relative similarity in mate behavior on CAORF and at sea.

Behavior During the Watch

Mate behavior during the watch is exemplified by the data for Watch #2, Matanilla Shoals area, shown in Figure 5. The upper curve shows the dimensionless contact load as a function of time during the watch. A contact load of zero through ten indicates a low level; 15 through 30 indicates a medium level; 30 and above indicates a high level. The contact load reached a low-level peak around 0900 and a high-level peak around 1130. The lower curves show: 1) the mate workload on CAORF during the four-hour watch, for all tasks, and averaged over the six mates that stood this watch; and, 2) the mate workload at sea during the similar watch, for all tasks, and for the one mate that stood watch. Inspection shows that the mates usually had a higher level of activity on CAORF. Much of this difference may be attributed to a learning/experience effect, which is discussed later. The workload peaks near 0900 and 1115-1145 correspond to the contact load peaks; the workloads during these times are primarily due to contact assessment tasks (e.g., reflection plotting on radar). The workload peaks around 1000 were due to navigation tasks (e.g., plotting a LORAN fix). The similar workload trends of the CAORF mates and the at-sea mate during the watch (i.e., peaks around 0900, 1000, and 1115-1145) show the correspondence between CAORF and at-sea behavior as a function of the situation conditions.

Behavior Averaged Across Similar Situations

Greater confidence in the behavioral comparisons may be had when the CAORF data are compared with averaged at-sea data, reducing the potential bias. The three CAORF watches and the entire at-sea data base were partitioned into segments based on the situation

TASK	SEA CONDITION/ CONTACT LOAD	WORKLOAD (%)	
		CAORF	AT-SEA
ALL TASKS	OPEN SEA/LOW	27.0%	15.6%
	OPEN SEA/HIGH	48.2	32.60
	RESTRICTED WATERS/ LIMITED VISIBILITY	47.6	54.00
RADAR	OPEN SEA/LOW	12.0	6.00
	OPEN SEA/HIGH	34.4	20.00
	RESTRICTED WATERS/ LIMITED VISIBILITY	30.0	22.00

Figure 4. CAORF and At-Sea Workload Comparison Summary (Spearman Rank Correlation Coefficient: T= .9(p<.05).

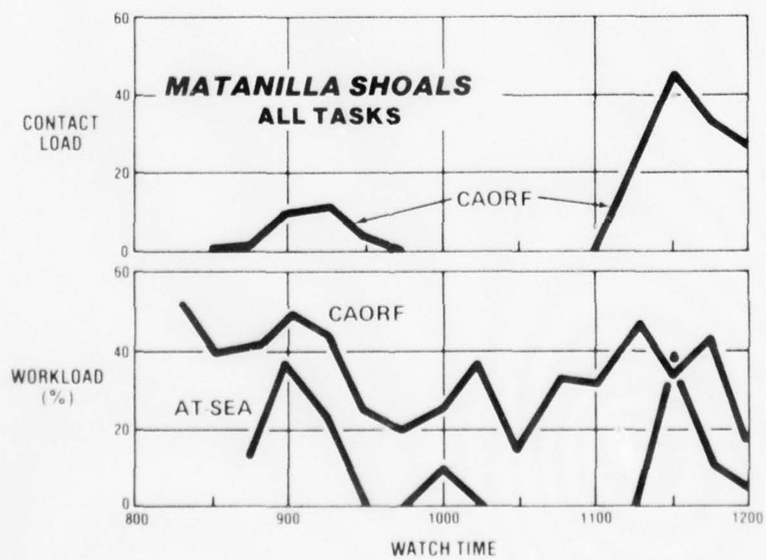

Figure 5. Contact Load and Mate Workload During Watch #2, Matanilla Shoals.

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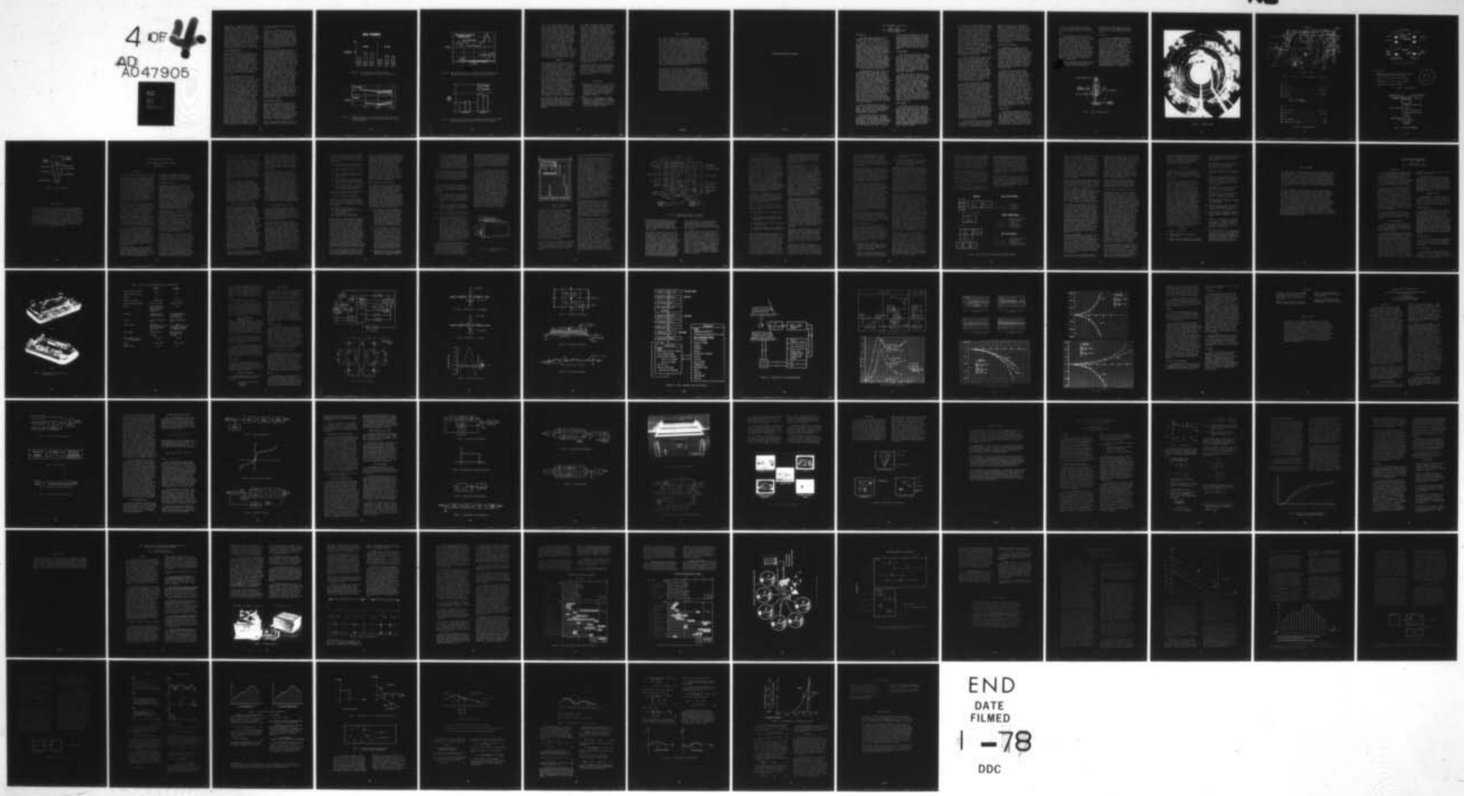

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conditions. Three distinct groups of segments were identified from the CAORF watches on the basis of the situation conditions: 1) open sea, good visibility, low contact load; 2) open sea, good visibility, high contact load; and, 3) restricted waters, limited visibility, high contact load. The average workloads for all tasks during these segments show that the mate workload differences between the three groups of situations on CAORF are similar to those at sea (see Figure 6). These similarities extend to specific task areas as well (e.g., radar tasks).

Learning/Experience

Figure 6 shows that the workload in each group is greater on CAORF than at sea. This nearly constant offset is attributed to a learning/experience effect that occurs when the mate initially reports on the CAORF bridge. This effect is similar to what is expected to occur when a mate first reports on an unfamiliar ship. He has to learn the instrumentation, the location of the controls, and the setup of radar; he has to become familiar with the ship operating procedures, and so on.

The learning/experience effect has been hypothesized to occur in two parts - short-term and long-term. The short-term effect occurs at the beginning of his first watch, eventually settling down to a more normal level of activity. Figure 7 shows the mate workload with the short-term learning/experience period segmented. The three situation categories in this figure are: 1) learning/experience - the first hour of the CAORF watch, which always had a low contact load; 2) low contact load situations that occurred after the first hour; and, 3) high contact load situations. The relatively high workload that occurs during the short-term learning/experience period is evident from Figure 7. The CAORF mates are as active during this period as when under the high contact load conditions. The impact of this short-term learning/experiénce period is exemplified by the workload difference between this group and the low contact load group, both of which occurred under low contact load conditions. Removal of the short-term learning/experience effect has considerably reduced the difference between CAORF and at-sea workloads. The remaining difference is attributed primarily to the long-term learning/experience effect.

Comparison of the workloads for all tasks with those for radar tasks in Figure 7 reveals that radar behavior was not overemphasized by mates on CAORF. The higher CAORF radar workload is in proportion to the higher CAORF workload for all tasks. Hence, the radar workload received the same relative emphasis on CAORF as at sea. The absolute differences are attributed to the learning/experience effect on all tasks.

The behavior of one CAORF mate was investigated with regard to the long-term learning/experience effect. This mate stood the #2 Watch (Matanilla Shoals) twice, the two times separated by three months during which he had some additional experience on CAORF. Figure 8 shows this mate's radar workload during the first and second times he stood this watch (i.e., upper and lower curves, respectively). The radar workload for the mate at sea is also plotted. These curves show a substantial difference in the radar workloads between the mate's two watches, indicating a long-term learning/experience effect. Furthermore, the CAORF mate's second watch radar workload was quite similar to that which occurred at sea (i.e., almost no radar activity until the contact load increased near the end of the watch). These data should be cautiously interpreted since they were from only one mate on CAORF and one mate at sea. Nevertheless, they suggest a long-term learning/experience effect. Additional research should be conducted at sea to verify the learning/experience effects on mate behavior when he first reports on an unfamiliar ship.

Experimental Effects

The initial experiment conducted on CAORF investigated the benefits of electronic aiding on ship performance under a variety of situation conditions. Three levels of electronic aiding were studied: 1) visual only; 2) radar and visual; and, 3) collision avoidance system (CAS), radar, and visual. The CAS condition was found to result in superior performance based on a variety of measures.

One of the major purposes of this validation study was to investigate the

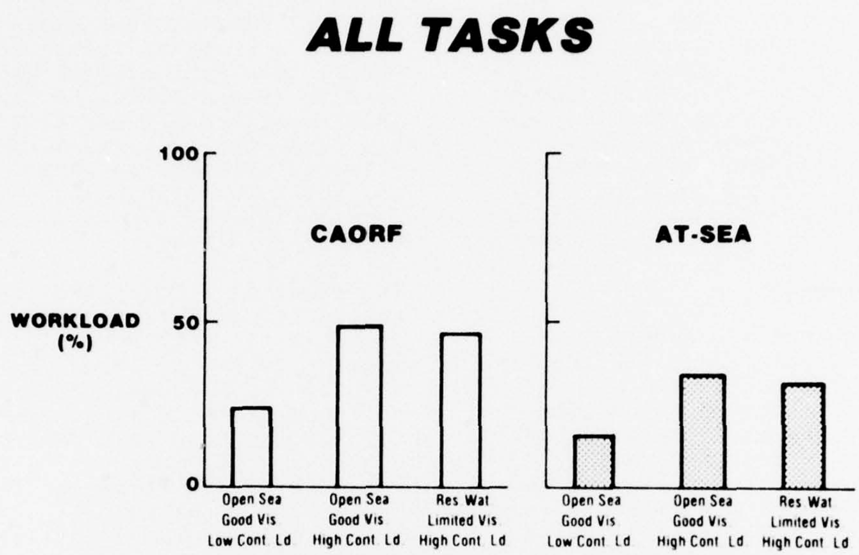

Figure 6. Average Workload for All Tasks, as a Function of Situation Conditions.

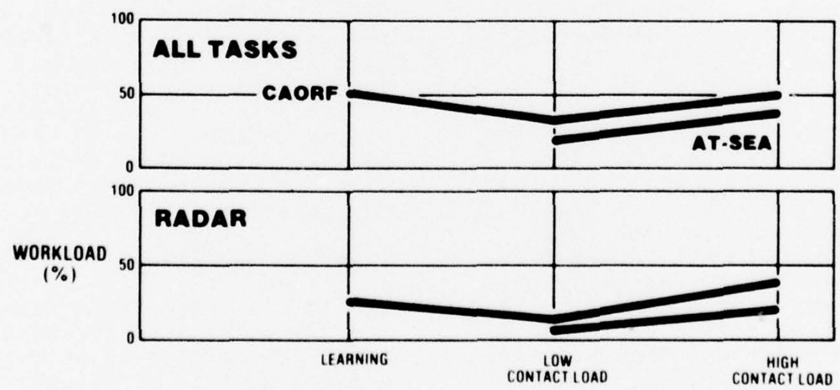

Figure 7. Average Workload as a Functioning of the Short-Term Learning/Experience Period, and Low and High Contact Load Situations.

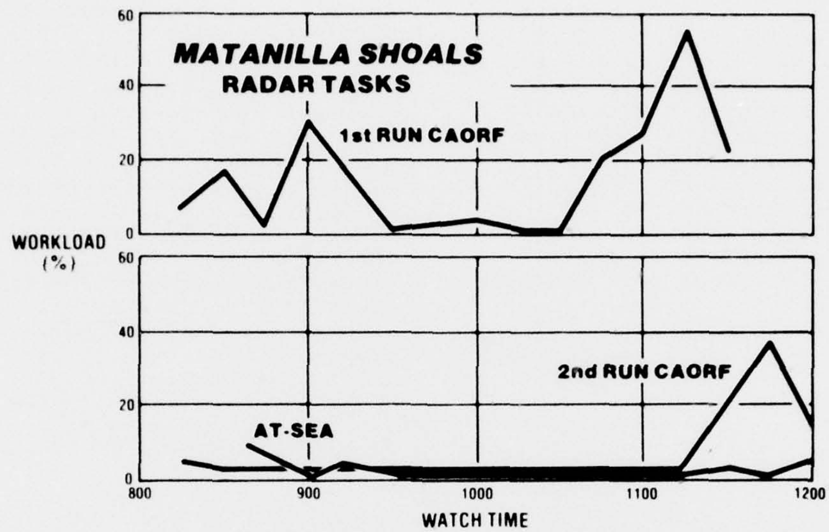

Figure 8. Mate Radar Workload During Watch #2, Matanilla Shoals, Showing the Long-Term Learning/Experience Effect.

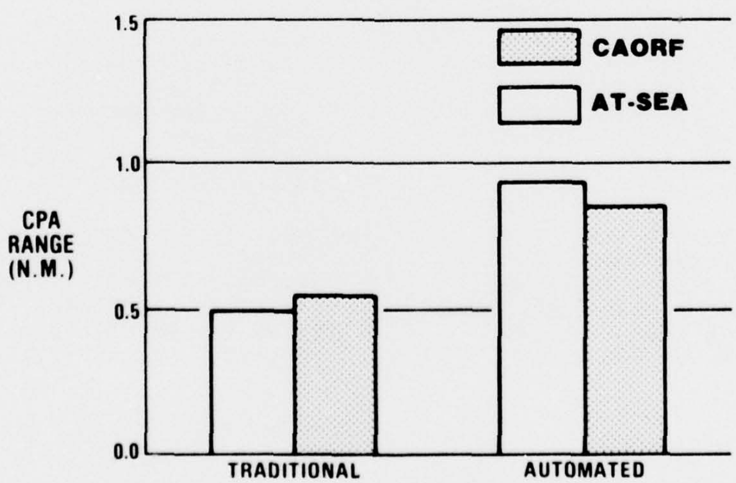

Figure 9. Range at Closest Point of Approach for Traditional (Radar) and Automated (CAS) Bridges, CAORF and At-Sea Data.

validity of CAORF experimental findings. This was accomplished by comparing experimental effects obtained from CAORF research with effects observed in the at-sea data. An important CAORF research finding supported by the at-sea data was that CAS equipped ships attained larger ranges at the Closest Point of Approach (CPA) than those ships equipped with radar only. Figure 9 shows the high degree of similarity in the ranges at CPA for CAORF and at-sea data for radar-only and CAS equipped ships. Of greatest importance, however, the at-sea data demonstrated an effect similar to that obtained from research on CAORF - that is, a greater range at CPA for the CAS equipped ships. The experimental effects obtained on CAORF, therefore, are substantiated by the effects observed in the at-sea data.

SUMMARY

The findings from this validation study demonstrate a degree of similarity between mate behavior on CAORF and mate behavior at sea. The mate's activity level on CAORF changed in accordance with situation conditions similar to behavior that occurred at sea. The CAORF mates were very active, at a level equivalent to that of the most difficult situations at sea. This generally high level of activity was attributed to a learning/experience effect that was predominant when the mates first reported on CAORF, and then subsided over time. This effect was similar to the expected behavior of mates at sea when first reporting on an unfamiliar ship. The mate's radar behavior on CAORF was also found to be similar to that occurring at sea, a function of the changing contact load conditions.

Experimental effects obtained in the initial CAORF experiment were verified by the at-sea data. These validation findings are, perhaps, the most important since they directly support the validity of CAORF research.

The CAORF simulator was designed primarily as a research tool. Its wide range of simulation, control, monitoring, and analysis capabilities make it an excellent training device as well. Although expensive, operation of CAORF is much less expensive than the operation of a ship at sea for research and training purposes, as has been demonstrated during experiments for the port of Valdez, Alaska. Other factors, such as the control of environmental conditions and the capability to train in failure modes of operation, weigh greatly in favor of the use of simulation. The acceptance of CAORF by the maritime community for research and training clearly demonstrates the need for resource conservation through simulation. The CAORF validation study represents a fundamental step in verifying the feasibility of simulation for solving a variety of problems, and hence, conserving resources.

The results of this validation study support the quality of the CAORF simulation and the resultant empirical research findings. This represents the first demonstration of the behavioral validity of a marine simulation facility.

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PAPERS PUBLISHED BUT NOT PRESENTED

360° NONPROGRAMMED VISUAL DISPLAY

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INTRODUCTION

For several years the Naval Training Equipment Center (NAVTRAEQUIPCEN), it's numerous contractors, and the Air Force and it's numerous contractors have been developing wide-angle visual systems for training. Many approaches have been tried with varying degrees of success. These approaches can be divided into two broad categories, namely, single channel systems and multiple channel systems. Because of the limited information capacity of single channel, real-time display systems; the limiting resolution of such systems is quite low which results in poor image quality. In multiple channel systems, the problems become those of color, luminance, and edge matching so that the wide-angle display has a continuous, uninterrupted appearance. Another problem for multiple-channel systems is that a wide-angle probe capable of close approach to model boards (on the order of a few millimeters) is not available.

In the Advanced Simulation Concepts Lab at NAVTRAEQUIPCEN, we have been trying to develop novel wide-angle visual systems, that perhaps saner people might not attempt. The display system to be discussed today is an outgrowth of several technology advances of industry such as the development of charge-coupled devices (CCD's), the development of highly synchronized mechanical laser scanners, and the development (in our own lab) of the annular projection lens shown in Figure 1. This lens consists of two confocal hyperbolic reflectors to eliminate astigmatism which is usually a plague of extreme wide-angle lenses and a series of lens groups to eliminate other aberrations. The final image is a plane, annular image as shown in Figure 2. Radial lines on this image represent vertical field angles and concentric circles represent varying horizontal field angles at a constant vertical field angle.

What I am going to discuss in this paper is how to create annular images with a probe; how to dissect and transmit annular images; and finally, how to reconstruct and project annular images to give a nonprogrammed 360° visual display.

The applications of such a system in training devices are numerous. The application that is currently driving the system development is the helicopter nap-of-the-earth (NOE) trainer. In NOE flying, the helicopter flys between trees, down ravines, etc., and the pilot chooses his own path. A system such as Disney's 360° Monsanto exhibit would not be appropriate because the flight path would be prechosen or programmed. Systems using computer generated imagery were also eliminated because the degree of detail and fidelity required for the trainer are currently somewhat beyond the state of the art. Thus, the current application dictated a model board, probe, projection lens type of system.

SYSTEM APPROACH

The system we are developing is shown in Figure 3. The trainee sits in a simulated cockpit at the center of a spherical screen. The scene that he views is projected from the projection lens. The laser assembly is the illumination source. The probe over the model board flies according to the controls input of the trainee, so that if the trainee wants to fly around a certain tree in his scene, if he makes the proper control adjustments, the probe will fly around that tree on the model board.

Assuming that we have a probe that can create an annular image of the model board, the problem is how do we transmit the annular image to the projection lens for projection onto the screen. The approach taken in this system is a multiple channel approach so that we can transmit adequate information; but, (and here's the novelty) the channels are interlaced to eliminate color, brightness and edge matching of conventional multiple channel systems. The system performance goals are shown in Figure 4. The limits shown on the slide are not theoretical limits but practical limits based on current designs. That is why probe and projection fields of view and resolutions are different. However, we feel that these goals are adequate for training.

IMAGE TRANSFER

If we assume that we have a projection lens that can project an annular image and that we have a probe lens that can produce an annular image from a model board, then the remaining problem is to transfer the image from the probe to the projector. If we use a single channel at television field and frame rates, then we have the channel matching problems. So the approach we adopted was a channel interlace approach with multiple channels; this eliminates both the single channel bandwidth problem and the multiple channel matching problems.

How do you interlace channels? In the 360° annular image system we interlace twelve video channels. Before we discuss the channel interlace procedure, it would be better to understand how one channel operates. Figure 5 shows the concept of the image transfer system. The annular image from the model board is formed by the probe. It is relayed by a relay lens to a second image plane. A pechan prism in the relay section rotates causing the second image to rotate in the direction shown. A linear array of CCD's is placed in a radial direction across the image. As the CCD array is scanned, we get a vertical field scan. At the end of a vertical scan, the image has rotated to a different horizontal field position where another vertical scan is accomplished. With this arrangement, a single CCD linear array scans out the whole annular image.

In the projection system we scan a radial laser line in a fixed radial position. The line is relayed to a second annular image plane with an intermediate pechan prism rotating so that the single laser line is rotated to all annular image positions. The signal from the linear CCD array is used to modulate the radial laser line. The counter rotating projector prism is synchronized to the probe prism so that the image is properly positioned in the screen area. Thus, a single channel can produce a complete 360° image on the screen. The purpose of additional channels is to reduce the scan rates, rotation rates, and modulation bandwidths required for each channel.

In order to get multiple, interlaced channels, we arrange twelve linear arrays of CCD's in almost equally spaced radial arrays. On the projector side, we have equivalent twelve laser scan lines arranged radially. All radial arrays are positioned as shown on the interlace mask in Figure 6. Adjacent lines are staggered slightly by three arc minutes. The pechan prism is rotated at a rate so that the image rotates six arc minutes for every vertical scan time. At that rate, it will interlace with the second radial array and it will overlay the third radial array. Six of the radial lines will overlay each other (0°, 60°, 120°, 180°, 240°, and 270°); the other six will also overlay each other but will interlace with the first six. Since each of the twelve arrays constitutes a single channel (CCD, modulator, laser) and each channel covers the whole image, then we have a channel interlace system each with one-twelveth the scan rate and modulation bandwidth required of a single channel television frame rate system.

The system line and scan rates employed in our twelve channel system can be developed as follows. If we require three arc minute line spacing in a 360° system, then we must have 7,200 lines/frame. For twelve laser channels, we need only 600 lines/channel/frame. If one goes through the math, the line scan time of 55 u. sec. and the mechanical laser scanner rate of 750 RPS for a 24 facet mirror can be calculated. The horizontal scan rate (prism rotation rate) can be calculated knowing that the image must rotate six arc minutes in the time of one line-scan. This will automatically produce a 2:1 interlace and give an equivalent sixty fields per second.

SUBSYSTEMS AND COMPONENTS

The projector arrangement, Figure 7, shows how all twelve laser channels are scanned with one twenty-four facet laser scanner operating at 45,000 RPM. Only two of the twelve lasers which are arranged radially around the scanner are shown in this figure. The optics between the scanner and the first annular image plane convert the targential laser scan patterns into twelve radial scan patterns. The twelve stationary laser scans are then rotated and relayed to fill the annular image plane of the projection lens which then projects the pattern onto the spherical screen.

The artists concept of the probe arrangement is shown in Figure 8. The twelve-sided pyramidal mirror at the top bends the optical path for each CCD array so that they can be physically arranged in a cylinder around the optical axis of the probe. Again, we have the pattern of one annular image plane being relayed into a second annular image plane with the rotating pechan prism between. The annular probe lens, in particular the front element, is a new optical system which is currently under design. The first order analysis indicates that we can get to within two millimeters of the model board with the probe entrance pupil. The design goal is for a diffraction limited F/9 system covering the spectral bandwidth of the CCD's. Considering the vertical scan rates and thus the integration times available, it is necessary to go to low light level devices such as CCD's. It is questionable whether an F/9 system of this type would have been feasible without low light level CCD's.

CURRENT STATUS

The system and component designs are all complete with the exception of the probe lens. The 45,000 RPM laser scanner has been designed and is being fabricated by the Ampex Corporation in Redwood City. The prism rotation motors are being fabricated by Baldwin Electronics in Little Rock. The projection lens is under contract to Space Optics Research Labs in Chelmsford. Other

components are being bought and assembled in-house. The final assembly and demonstration is scheduled for August 1978 in Orlando.

COLOR

The system that has been described so far is a monochrome system which will be used to demonstrate feasibility. A study has been performed to investigate the problems in going to a full color system. We are currently using twelve argon lasers for the twelve channels; the study indicates that if we make four channels krypton lasers, then we can project full color. Since each channel covers a 30-degree sector on the screen before the next channel covers the same sector, we will have a field sequential color system. By increasing the prism rotation rate and, if higher resolution is needed, the laser scan rate, it is possible to eliminate color flicker in the system.

Another modification that must be made to complete the transformation to color is to put appropriate filters over the CCD's.... Because of the spectral band of the CCD's (500-1000 nm), it will probably be necessary to go to a false color system on the model board.

CONCLUSION

This paper has presented a design approach to a large, spherical screen laser display system utilizing a probe and model board for input imagery. Paper studies and designs have verified the feasibility of this complex 360° Nonprogrammed Visual Display, but because of it's complexity and the tight tolerances (which I have not covered in this paper) on component and system performance, it was decided to have a hardware feasibility demonstration. The features of the system which nonbelievers are most skeptical about are the scanner synchronization with the prism motors and CCD's, the complexity of optical alignment, the optical probe performance and the ability to have relatively trouble free operation. The system fabrication is underway with a scheduled demonstration in August of 78.

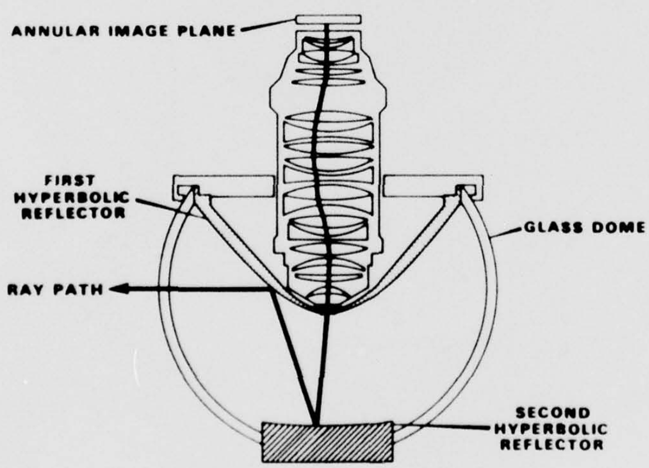

Figure 1. Annular Projection Lens

Figure 2. Annular Image

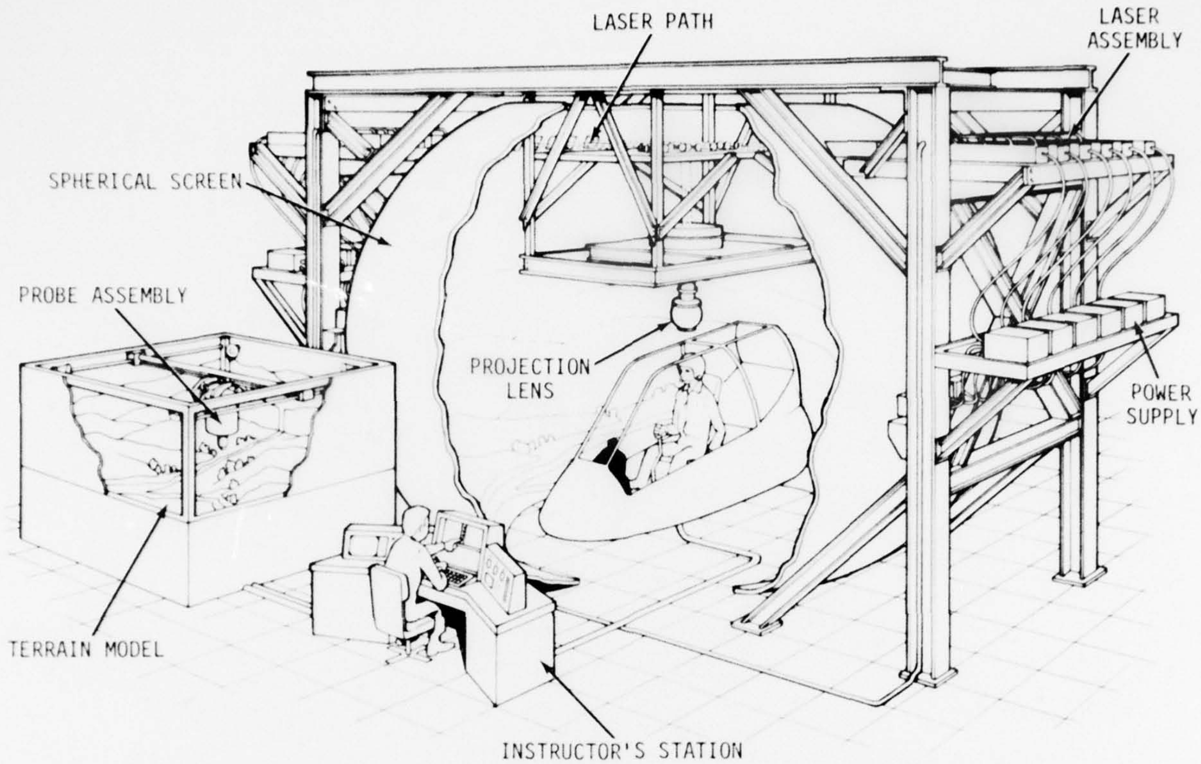

Figure 3. System Concept (360° Nonprogrammed Visual Display)

PROJECTOR

- FIELD OF VIEW .... $360^{0} \times 90^{0}$
- RESOLUTION .... 5 ARC MIN
- LUMINANCE .... 10 FT LAMBERTS
- DARK FIELD

  1 MHZ-0.1 FT LAMBERTS
  10 MHZ-0.25 FT LAMBERTS

PROBE

- FIELD OF VIEW .... $360^{0} \times 60^{0}$
- RESOLUTION .... 3 ARC MIN
- F/# 9
- PUPIL DIAMETER .... 1 MM
- ENTRANCE PUPIL DISTANCE .... 2 MM

Figure 4. Performance Goals

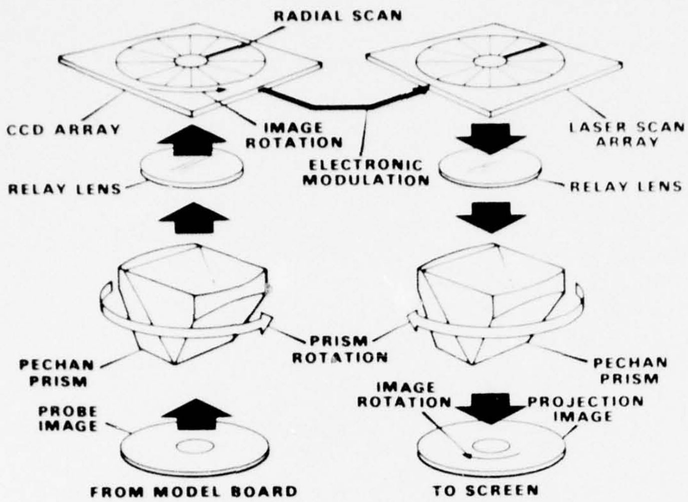

Figure 5. Image Transfer System

INTERLACE METHOD:

1. IMAGE ROTATION RATE ROTATES SCAN LINE 6 ARC MIN DURING ONE RADIAL SCAN (VERTICAL SCAN)
2. SCAN LINES 0^o, 60^o, 120^o, etc WILL OVERLAY
3. SCAN LINES 30^o-3', 90^o-3', etc WILL OVERLAY
4. ALTERNATE SCAN LINES WILL INTERLACE

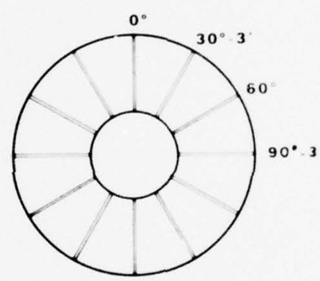

Figure 6. Interlace Mask

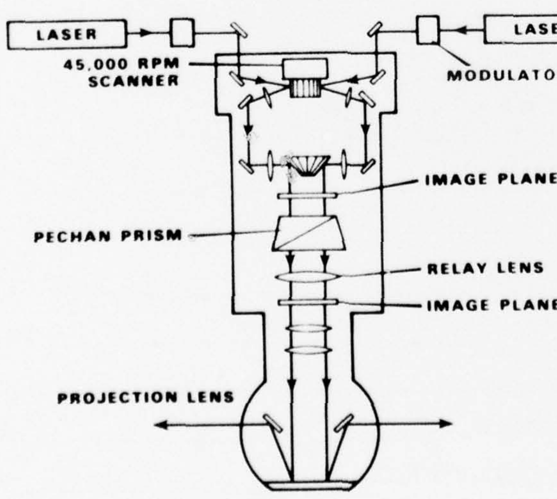

Figure 7. Projector Arrangement

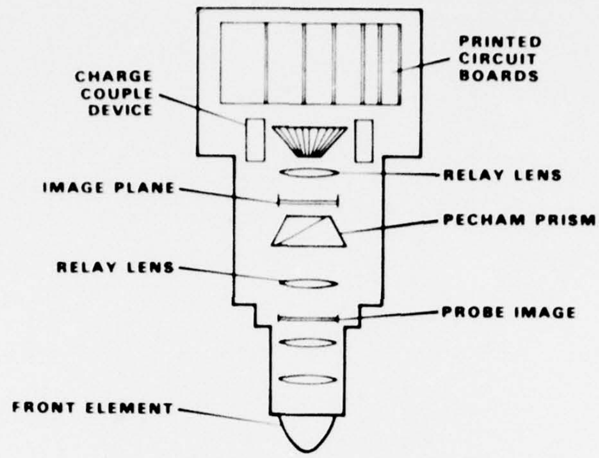

Figure 8. Probe Arrangement

ABOUT THE AUTHOR

MR. FRANK J. OHAREK has been with the Naval Training Equipment Center for the past 11 years. He has designed optical systems and lenses such as a 40:1 optically compensated zoom lens and a panoramic projection lens using the ACOOS V lens design program. His more recent work has been as coinventor and principal investigator on the 360° Nonprogrammed Visual Display System. Prior to that, he was with General Electric, Valley Forge, from 1964 to 1966 where he worked in optical data analysis and optical instrumentation for reentry vehicle discrimination and flight analysis on the TRAP program. From 1959 to 1961, he was with Martin Company in Orlando and worked in optical and laser systems. He has B.S. and M.S. degrees in physics from the University of Florida and Rollins College.

DESIGNING SIMULATORS FOR PRACTICALITY

DR. CHRISS CLARK and DR. JAMES A. GARDNER

Honeywell Inc.

INTRODUCTION

Exploiting Simulation in Maintenance Training

The trend. There is a growing trend to exploit the potential benefits of simulation technology in the maintenance training environment. The Air Force, for example, is currently contracting for a simulator system designed to train organizational-level (O-level) maintenance procedures for ten subsystems of the F-16 aircraft. Procurement of simulators for training F-16's intermediate-level (I-level) maintenance procedures is under advisement. Current plans call for using simulators to train E-3A and selected F-15 maintenance as well. These procurements signify a fundamental change in the philosophy of maintenance training, which has relied almost exclusively to date on actual equipment trainers.

The incentives. The principal incentives for this revised approach to maintenance training are expressed concerns over the high-dollar costs of training and combat readiness, coincident with increasing pressures to curb defense spending. Approximately $12.6 billion are consumed annually by the military for direct training costs. The Offices of Management and Budget, and Secretary of Defense have issued directives requiring that all trainers and simulators be cost-justified prior to funding(1). Air Force Systems Command has likewise placed renewed emphasis on development and application of life-cycle cost techniques within all technology areas(2).

One significant impact on training costs is the number of trained personnel required to meet field demands. The Army, for example, has expressed interest in reducing maintenance personnel by seven to ten percent. This is a reasonable goal, however, only if the remaining, more limited maintenance force is better trained to compensate for the reduction. Unfortunately, evidence suggests that in many instances effectiveness of current training is far from adequate even for the existing maintenance forces.

An increased emphasis on "hands-on" practice of maintenance procedures (e.g., the Navy's Technical Hands-On Training System(3)) is intended to improve training effectiveness. In general, however, hands-on practice is severely limited with actual equipment trainers. Simulators, on the other hand, permit the practice of a full range of test procedures, *including those that would be dangerous or expensive to practice on actual equipment.*

Assessing Practicality

The question. A number of experimental programs have demonstrated the feasibility of using simulators as alternatives to actual equipment trainers for training maintenance personnel. The feasibility of applying simulation to I-level maintenance training was first demonstrated by Honeywell as part of an NAVTRAEQUIPCEN-sponsored program to simulate the ALQ-100 electronic warfare set and associated test stations.(4) The feasibility of simulating complex electronic maintenance equipment is no longer in doubt. The question becomes: are simulators practical alternatives to actual equipment for training purposes? This is the issue suggested by the conference theme, "Resource Conservation Through Simulation."

Practicality defined. Simulated maintenance equipment becomes a practical alternative when the associated life-cycle costs (LCC) are less than those of corresponding actual equipment trainers. This reduction can be effected primarily by substantial reductions in both procurement costs and the long-term maintenance costs for simulated equipment. In addition, the use of simulated equipment as a training device must at least maintain and preferably improve upon the level of training effectiveness achieved with actual equipment. Improved training effectiveness will be reflected in further LCC reductions.

Related research. A major on-going Air Force research program(5) is addressing the practicality issue with respect to I-level electronic maintenance training. The current program phase focuses on design, fabrication, and testing of a simulator-based system to provide hands-on training of Level-3 Apprentices to maintain the 6883 Converter/Flight Control Test Station (in support of the F-111D aircraft) and associated Line Replaceable Units (LRUs). The system incorporates simulations of the 6883 Test Station, four associated adapters, and three LRUs. A later program phase will include a comparative evaluation of current versus simulator-based 6883 training. Comparisons

will include LCC analyses as well as training effectiveness evaluations.

The current paper. This paper seeks to identify some of the major factors influencing the practicality of simulators in the maintenance training environment -- factors that can effect resource conservation. This requires an understanding of what simulator-based training systems are and what resource demands are levied by current training approaches. To effect maximum resource conservation, the design of simulator-based training systems must focus on the identified sources of leverage in existing training systems.

Numerous references are made to the Air Force's 6883 program to illustrate how resource conservation can be considered in the design of a training system. The 6883 Test Station is an appropriate vehicle for demonstration because it represents a general class of very expensive, complex, electronic test stations commonly found in I-level maintenance shops and currently used as actual equipment trainers as well. Therefore, many considerations made with regard to providing simulator-based training for the 6883 can generalize with reasonable accuracy to a large number of similar devices.

SIMULATOR-BASED TRAINING SYSTEMS

Definitions of simulation and simulators abound(6). Nonetheless, certain general features characterize nearly all simulator-based training systems. First, simulator-based training systems incorporate devices that duplicate, in varying degree, the appearance and operation of selected actual equipment. The resultant "simulators" range in complexity from simplistic cardboard mock-ups to the very sophisticated flight simulators used in pilot training. The essential feature is that the simulators provide "sufficient" realism: 1) to evoke and permit practice of specified job-related tasks, and 2) enhance transfer of the learned skills/knowledge to real world job environments. In the design of all simulators, certain aspects of the actual equipment are deliberately omitted; that is, the simulators are characterized by less than 100% engineering fidelity. The simulators become training devices when these omissions are based on careful identifications of how the devices are to be used in the training environment -- what persons with what entry-level skills/knowledge are to be trained to perform what set of tasks to what level of proficiency under what conditions?

Second, simulator-based training systems may incorporate supporting instructional features -- trainer-unique features and capabilities not inherent to the actual equipment. These features could include carefully controlled learning situations, step-by-step monitoring of trainee actions, performance feedback, automated instruction, and well designed student and/or instructor station consoles. Again, however, the requirement for these various adjunct features must be based on a clear specification of intended simulator trainer use.

Third, within the context of Honeywell's Automated Electronic Maintenance Training (AEMT) concept, simulator-based training systems are closed-loop (i.e., computer-driven and computer-sensed) systems designed primarily to provide hands-on practice of required job skills. Not only does the computer control the training environment (e.g., by simulating a carefully selected set of maintenance problems to which the trainee must apply relevant skills and knowledge), but it also monitors the trainee's step-by-step actions, compares these actions with prescribed procedures, and informs both the trainee and his instructor concerning the trainee's performance. This feedback is intended primarily as a learning aid and only secondarily as data for student records. The specific content, format, and frequency of that feedback vary in accordance with this aim.

TRAINING DEMANDS ON RESOURCES

The costs of current maintenance training systems fall into two general categories: personnel (student, instructor, and support) and equipment (procurement and support). Of these two, personnel costs account for the major portion, although the degree of savings leverage associated with that category varies with the particular system.

For example, personnel costs vary from approximately half of the total system costs in the case of the A-7 Heads-Up Display (HUD) system (7), to 97 percent of total costs in the case of the Navy's Basic Electronics and Electricity (BE&E) Program (8). Because the HUD and ALQ-100 Electronic Warfare systems are relatively equipment-intensive systems with low student flows, comparable savings can be achieved in both equipment and personnel categories. In stark contrast, the BE&E program is extremely personnel-intensive, inputting over 7000 students per year, per training site. Although the actual training equipment in the BE&E course may be cost effectively simulated, the real leverage rests in reducing personnel costs, especially students. Therefore, any BE&E simulation system must maximize training effectiveness to be a practical alternative.

The application of simulation to maintenance training could impact training-related personnel costs in a variety of ways. For example, simulator-based training systems have the potential to:

- Improve the instructor/student ratio, thereby reducing instructor costs.
- Reduce student on-board time, thereby reducing student costs.
- Reduce required maintenance force for training equipment, thereby reducing support costs.
- Minimize personnel required to incorporate curriculum and/or engineering changes, again reducing support costs.
- Reduce required number of field maintenance personnel, thereby reducing the required training throughput.

These areas of potential savings are addressed in subsequent sections of this paper.

DESIGNING FOR RESOURCE CONSERVATION

The key to resource conservation through simulation is careful training system design. To be effective, this design process must be guided by multiple considerations, including the following:

- Meeting training objectives
- Meeting without exceeding required functional capabilities
- User acceptance
- Improved training effectiveness
- Training system supportability

However, the first decision to make regarding the application of simulation to maintenance training is when not to simulate. Simulator-based systems cannot be assumed a priori to be the most practical approach to meeting the training need. Factors to be considered include: the projected student pipeline, the availability of inexpensive alternative training media, (e.g., sound-slides, video tape, movies, cardboard mockups), number of required training units, current training deficiencies, user acceptance of simulation, and the state-of-the-art in simulation technology. Indeed it is quite possible that no single approach is sufficient to meet the total training requirement; some combination of operational, simulated, and/or stimulated equipment together with traditional classroom approaches may provide the most appropriate training environment.

There is recognition of the fact that simulation should be implemented selectively. The Air Force Human Resources Laboratory (AFHRL) has recently awarded a contract to develop and apply a technique to identify areas of technical training within Air Training Command where high payoffs can result through use of simulation. This techniques is to be applicable across skills levels and will not be limited to avionics applications. The Army has likewise publicized its intent to sponsor a study to identify the areas of maintenance training for which reduced fidelity trainers can be cost-effectively substituted for standard, operational equipment currently used as trainers. These identifications are to be made on the basis of training level (institutional or unit), type and/or specialty (track vehicles, wheel vehicles, aviation, electronics), and skill (motor, cognitive or combination).

Design to Meet Training Objectives

The crucial first step in the design of any simulator-based training system is a front-end analysis. It is conducted to determine the training features to be incorporated not only in the simulator training device itself, but in the total training system. The resultant functional specification guides the subsequent detailed design and determines in large part the ultimate effectiveness of the device, thereby impacting both equipment and personnel costs. A recent AFHRL-sponsored program recommended and documented a process for the design of trainers based on behavioral information (9). The identifiable products of the front-end analysis may include:

- A listing of tasks/skills/knowledges to be trained. These constitute training requirements and are specific reflections of the fundamental purpose of any training system: to evoke prescribed changes in human behavior. They are a function of the ultimate behavioral objectives for the trainees upon completion of training and the level of skills/knowledge possessed by trainees upon entering training.
- An established set of training priorities. For example, a common goal in maintenance training is to place primary emphasis on detection of faults and isolation of their sources and to place secondary emphasis on performing the appropriate remove-and-replace (R&R) task. A few representative repair actions are usually required; in cases where the trainee is not asked to perform the R&R task, he is nonetheless asked to indicate what the appropriate repair action would be, given the simulated fault.
- Documents that specify the functional requirements of the related hardware, software, and courseware. These

documents are referred to as functional or performance specifications. While the training requirements and priorities are statements related to the trainee's prescribed performance during training, the functional specification establishes the capabilities and performances required of the simulator, or other training device, and of the system of which it is a part.

Although the functional specification does not contain the detailed design information such as would be required to cost and fabricate the simulator system (e.g., drawings, diagrams, theory of operation, parts list), it does constrain the detailed design.

The development of training requirements, priorities, and functional specifications requires that one address a number of critical questions. Typical questions include the following:

- What is the intended scope of the training system and how is the simulator training device to be used within that system? Will the simulator be the sole or even primary training equipment?
- What is the entering skill/knowledge level of the target trainee population? To what level of expertise are they to be trained?
- What are the deficiencies in existing training and what accounts for them?
- What is the set of on-the-job procedures that an individual of the designated exit-level skill is expected to execute? These prescribed procedures are a function of the accepted maintenance philosophy. The identified set will likely reflect both normal and degraded modes of operation. In the case of developing simulator-based maintenance training systems, significant effort is directed towards selecting a representative subset of realistic malfunctioning conditions to which the trainee is exposed so that he can practice fault detection, isolation, and troubleshooting techniques.

The identified maintenance procedures are further described in terms of specific actions (e.g., place 400 CPS and 60 CPS circuit breakers to ON position), associated man/equipment interfaces, and relevant cues (e.g., displays and indicator lights). These data are then cross-referenced with features of the actual equipment to identify a candidate set of equipment features and visual/functional fidelity levels to be reflected in the simulator design. Final selection of functional capabilities is based on such considerations as difficulty/importance of training the associated procedure(s), alternate training forums for the procedure(s) (including on-the-job training), cost considerations, and user biases.

In the case of selecting functional capabilities for the 6883 Simulator System, decisions reflect the preceding considerations plus an underlying philosophy of training by representative example. These selection criteria are perhaps best illustrated by the Data Transfer and Control (DATAC) drawer and power supply drawers. The DATAC (Figure 1) was selected for in-depth simulation because it is central to a variety of maintenance procedures. It is the principal technician interface through which automatic test requests are initiated, test modes are changed, and test results are displayed. Knowledge of its functions/operation is essential to operation of the entire test station. The training-by-example philosophy is reflected in simulation of the DATAC drawer interior. Although the hinged card frame assembly contains a full set of 56 simulated printed circuit cards (Figure 2), only 4 are removable and sensed by the computer. The remove-and-replace procedure is identical for any one of the 56 cards and, therefore, can be sufficiently well trained on a limited number of such cards.

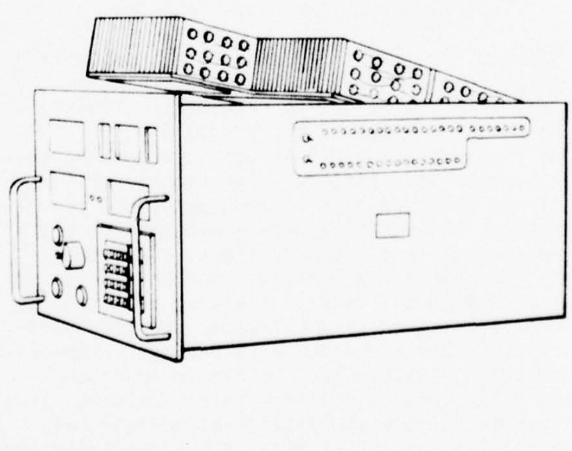

Figure 1. Simulated DATAC Drawer, Side View

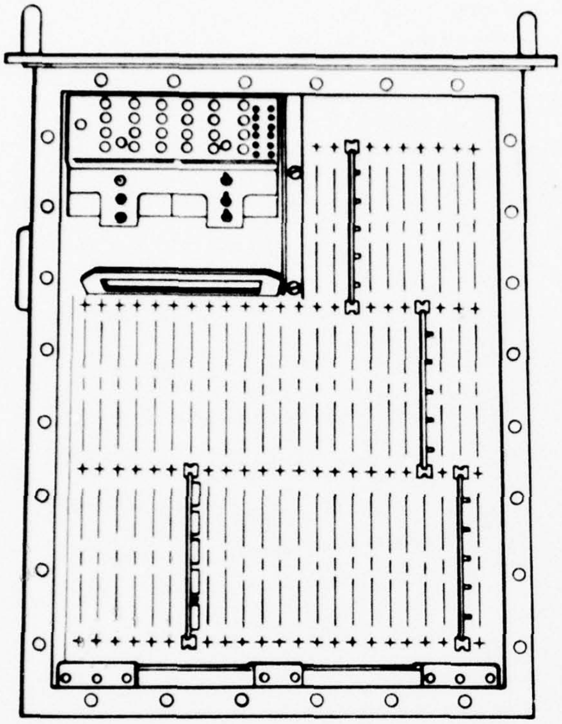

Figure 2. Simulated DATAC Drawer Interior, Top View

For similar reasons, only a single power supply drawer is simulated internally, although the 6883 has several power supplies. Maintenance procedures, simulation techniques, and the skills and knowledge required for troubleshooting are common among most power supply circuits in the 6883. This simulation philosophy is reflected throughout the functional design of the test station and LRU simulations. Figure 3 depicts the resulting variation in fidelity across the panels of the test station simulator. The 6883 Simulator consists of 28 metal photo panels, 3 pull-out drawers with simulated interiors, and an unmodified GFE oscilloscope, arranged in the appropriate 4-bay configuration. Selected front panels are represented completely with metal photos. Others are simulated using metal photos plus appropriately positioned functional components.

By making the types of tradeoffs just described, the 6883 Simulator System permits the trainee to practice the range of maintenance procedures that a 3-Level Apprentice must perform, without requiring unnecessary, costly simulator features.

Design to Meet, Not Exceed Required Capabilities

Several alternative detailed designs may satisfy the functional specification: the specification itself does not contain any explicit design decisions or choices among alternative design approaches. For example, the 6883 functional specification requires that the system permit the trainee to adjust a designated potentiometer within specified tolerance limits; the adjustment should be reflected on a corresponding meter. The detailed design of the simulated potentiometer (e.g., how it is sensed), the simulated meter (e.g., how it is driven), and related performance-monitoring software are not specified, although they are constrained by the functional requirements. In this case, the potentiometer and meter representations must bear sufficient visual similarity (visual fidelity) to and must also appear to function like (functional fidelity) their operational counterparts, with regard to the specified adjustment task. Moreover, the system must be able to sense the trainee's adjustment and to compare that adjustment with the prescribed procedure. How these functions are to be accomplished is not prescribed in the functional specification.

Caution must be exercised to avoid over designing the simulator system. To develop an engineering design for a system that exceeds the required functional capabilities merely increases cost without providing a corresponding increase in training effectiveness. For example, unnecessarily costly displays may be designed that provide rise times, resolution, or dynamic capabilities far beyond what is required for a simple GO or NO GO maintenance status check.

Carefully prepared functional specifications can often lead to dramatic reductions in the required fidelity of simulated controls and displays without negatively impacting training effectiveness. For example, a front-end analysis of the F-4N O-level Visual Target Acquisition System (VTAS) radar training requirement indicated that students already had received extensive experience with radar display interpretation prior to their entry to the VTAS course (10). It was only necessary for the students to detect the presence or absence of certain dynamic radar modes. Therefore, a simulation of these radar modes was simply constructed from a series of lighted segments which combine through computer control to create the appropriate display. By properly sequencing the lighted segments, the computer software duplicates the various dynamic, sweeping radar displays normally seen during VTAS checkout.

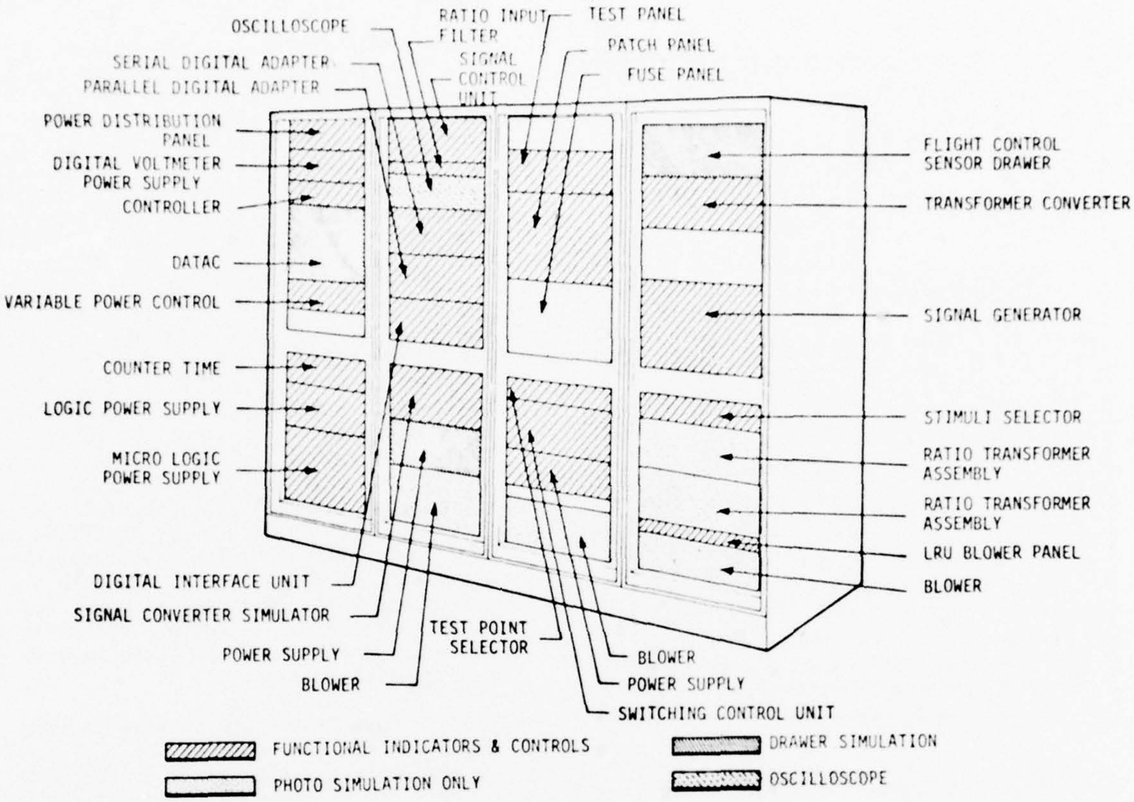

Figure 3. Panel-by-Panel Summary of Simulation Levels Required Across Test Station

Through a clear identification of the features necessary for effective training, similar cost-effective detailed design decisions can be made for such diverse topics as input/output response speeds, control resolution, meter motion, and waveform fidelity.

Overdesign is a potential pitfall in software design as well. Before any detailed software design is initiated, it must first be determined if the functional specification requires primarily procedural or modelled software. For many maintenance training tasks, it is only necessary to duplicate display-control interactions and to monitor trainee performance for specific step-by-step procedures defined in the system maintenance manual. Should the student make an error such as setting an incorrect switch or skipping a procedural step, the computer will halt the lesson, provide the appropriate feedback, direct the student to correct his error, and allow him to proceed with the lesson once he has made the specified corrective response. This procedural software design approach provides a low-cost solution to a range of maintenance technician tasks having clearly defined actions and equipment responses.

In contrast, some functional specifications may require the simulation to model the actual equipment operation. This modelled software design approach requires the development of a polynomial mathematical equation of each instrument as well as for the overall system control and display interactions. The student may set controls and make adjustments in any order he chooses, and the equipment will respond appropriately. Student performance measurement in a modelled system is correspondingly more complex due to the more ambiguous performance criteria. The greater complexity of modelling software is reflected in greater development and modification cost.

Design for User Acceptance

The argument for taking the most simplistic design approach which satisfies explicit requirements of a functional specification must be tempered slightly by concern for user acceptance. Traditionally, flight simulators have been characterized by extremely high engineering fidelity -- to the point that they could be considered aircraft without wings -- and the cost of such simulators sometimes exceed that of the operational aircraft themselves. This can be attributed to two major factors: 1) limited data concerning the features of the aircraft system that are required to train the mission, and 2) the demands of users for a training device that "feels like, looks like, smells like..." the real thing. The user's conviction is frequently that the actual equipment is the best training environment; simulators somehow represent a degraded training environment, but are "accepted" because they become the only reasonable alternative in light of government edicts to reduce costs.

The problem of overcoming the user community's resistance to simulator-based training where actual equipment is currently the norm and is a major concern for the maintenance training area, and must therefore, be considered in trainer design.

Design for Improved Training Effectiveness

Improved training can potentially effect substantial savings by:

- Reducing the number of required field personnel.
- Reducing training time, thereby making trained technicians available sooner and longer.
- Reducing the need to retrain inadequately trained personnel.
- Reducing the amount of time operational equipment and personnel are devoted to OJT.

Addressing current training deficiencies

The use of actual equipment trainers for maintenance instruction limits the effective training of many critical procedures. A well documented problem in current 6883 training, for example, is the frequent unavailability of a fully operational test station. This is a function of the equipment's inherent low reliability and the significant "down time" -- i.e., lost training time -- associated with required maintenance. Test station unavailability is especially pronounced in the training environment due to intermittent use of the station, station misuse by trainees, less experienced maintenance personnel, and training facilities' low priority with respect to receipt of needed replacement parts. Consequently, the effectiveness of current 6883 training and training for comparable equipment is suspect.

The low availability of actual equipment trainers together with concern for student and equipment safety limits the trainee's "hands-on" practice of general maintenance procedures. In particular, use of actual equipment trainers severely limits the range of equipment faults and emergency conditions to which trainees can be systematically exposed. Consequently, trainees are not permitted sufficient practice troubleshooting problems they are likely to encounter in the field. Duplication of a controlled set of equipment faults generally requires physical insertion of costly prefaulted hardware components. Permanent damage to the actual equipment is simply not an option. Simulator-based training systems, on the other hand, permit the insertion of preprogrammed malfunctions upon instructor command. The simulator-based system is decidedly more flexible in training situations.

Providing added instructional capability

A major advantage of simulator-based training systems is the closed-loop nature of the computer driven and computer sensed events. Three-Level Apprentices, for whom the 6883 Simulator System is designed, are not permitted to practice "free-play" troubleshooting techniques. Therefore, a system that forces strict adherence to prescribed procedures is appropriate. HRL's original RFP for the 6883 recognized this basic maintenance philosophy and required that any candidate simulation system not permit the trainee to advance if he deviates from prescribed procedures. This requirement reflects the theory that learning is optimized by not permitting practice of incorrect responses. A computer-based, closed-loop system is ideally suited to such a requirement.

Furthermore, because the computer can monitor step-by-step trainee performance and can provide appropriate preprogrammed feedback/guidance to assist the trainee as required, the instructor is freed from many of the routine tasks of "instruction." This could result in improved (i.e., lower) instructor/student ratios, thereby effecting personnel savings.

A related, often touted "advantage" of computer-based (or other programmed instruction) systems is that they permit self-paced learning. Accordingly, trainees need spend no more time in training than their own rate of progress demands. This is an advantage, however, only if the total training or career

plan is structured and managed to accept a continuing flow rather than periodic batch delivery of trained personnel. Little is gained by a self-paced training segment if upon completion the trainee must mark time before he enters a subsequent lock-step training segment or before he receives an appropriate field assignment.

Performance measurement. A critical factor in improving training effectiveness is appropriate performance measurement. Performance measurement refers to the reduction of the trainee's step-by-step performance data to meaningful indices. These indices can reveal problem areas that might otherwise go unnoticed in the overwhelming quantity of data that a computer-based system can monitor.

Among the various performance measures maintained by the 6883 Simulator System, for example, are counts of each trainee's procedural errors in various lesson segments; how often does he deviate from the prescribed sequence of actions outlined in the appropriate maintenance manual? Consistently high error counts might suggest that the trainee is simply negligent in attending to the manual's instructions or, alternatively, that the manual itself is not clearly written. The latter possibility can be explored by examining the error counts of other trainees to determine if they are erring on the same steps. If so, the computer-driven lesson material might be revised to provide clarification at specified points in the lesson to compensate for the manual's ambiguity.

In addition to serving as instructional aids, appropriate performance measures provide a means of assessing whether the trainee has met final performance criteria. This could reduce the chances that inadequately trained personnel would be released into the field.

Design for Supportability

Increased interest has been demonstrated recently in the reduction of life-cycle system support costs. This concern is reflected in the recent procurement of F-16 O-level maintenance simulators based upon the total system life-cycle cost, rather than mere hardware acquisition costs. To achieve this objective of low life-cycle support costs, a number of issues must be addressed during the system design including:

- Simulator System Maintenance - is contractor or organic maintenance the most cost-effective solution? What self-test capability is necessary? What spares inventory is appropriate?

- Simulator System Expandability/Flexibility can the simulator be cost-effectively modified or expanded? If major changes are made, do these require a complete system redesign?

- Configuration Management - if changes are made to the operational equipment, how are these changes implemented and controlled on the simulator?

Simulator system maintenance. Any practical alternative to actual equipment trainers must be reliable, easily maintained, and thereby consistently available for training. Meeting these criteria impacts significantly the costs associated with replacement parts and the required maintenance force. Total spares support for the VTAS O-level maintenance simulators delivered to the Navy and Marine Corps, for example, accounted for only 2.5 percent of the simulator system cost. This figure is in sharp contrast with the more usual 10-20 percent spares cost associated with support of actual equipment trainers procured at significantly higher costs. Moreover, the required maintenance time to date on the VTAS trainer has been negligible.

Provision for long-term maintenance of simulator-based training systems is a controversial topic across the Services. If the military assumes maintenance responsibility for these devices, is there need to establish a dedicated career field for simulator maintenance personnel? Moreover, what modifications must be made in existing policies to accommodate maintenance of this new breed of training devices? Air Force Logistics Command (AFLC) policy, for example, requires that spares be kept in inventory for only a limited period of time, after which they are discarded. It is possible that given the anticipated reliability of simulator systems, the demands on inventoried spares would be so few and infrequent that the spares would not be in the inventory by the time they are needed. An alternative approach to the maintenance issue is to procure full contractor maintenance. However, this requires a level of confidence in the contractor's continued commitment to the simulator-based trainer market. The long-term maintenance issue is complex and far from resolution at this time.

In the near-in case of the 6883 Simulator System, current plans call for a hybrid approach to maintenance, involving participation by both the Air Force and Honeywell. The simulation hardware is designed to be repairable to the component level by 5-Level Air Force Specialists. Prior to delivery of the system, Honeywell will conduct a maintenance training program that will equip a small (2-4) team of instructors to perform periodic, preventive, and corrective maintenance on the 6883 Simulator. These same persons will critique maintenance manuals to be delivered with the system. Final versions of the documentation will reflect their comments.

Major system maintainability design objectives include requirements for no unique maintenance skills of this specialist and requirements for the fewest possible preventive maintenance procedures and equipment alignments. Off-the-shelf, locally available system components are used wherever feasible. A detailed list of recommended spares will be delivered to the Air Force for procurement consideration.

Automated self-test and fault-isolation procedures are being provided for the system interfaces and simulation hardware. Software programs are being provided to permit daily automated status checks of the simulator prior to student instruction. Other, more detailed fault-isolation programs under development permit rapid fault isolation to major replaceable assemblies and cards.

All computer and peripheral equipment will likely be totally supported through a separate contract with Honeywell Information Services.

Expandability/flexibility. Modifications to actual equipment trainers can require major resource commitments. Extensive retrofitting of field equipment leads to costly, lengthy onsite modification of the corresponding training equipment, with the coincident loss of training time. Major model changes often result in scrapping the existing trainer for a replacement model. Even minor changes to the trainer to increase its capabilities can be expensive if the system is not designed to accommodate changes.

With proper design, the impact of changes can be minimized in simulator-based training systems. Many extensive revisions can be accommodated largely through simple software changes and low-cost simulated hardware changes. Even major model changes can be reflected without complete system replacement.

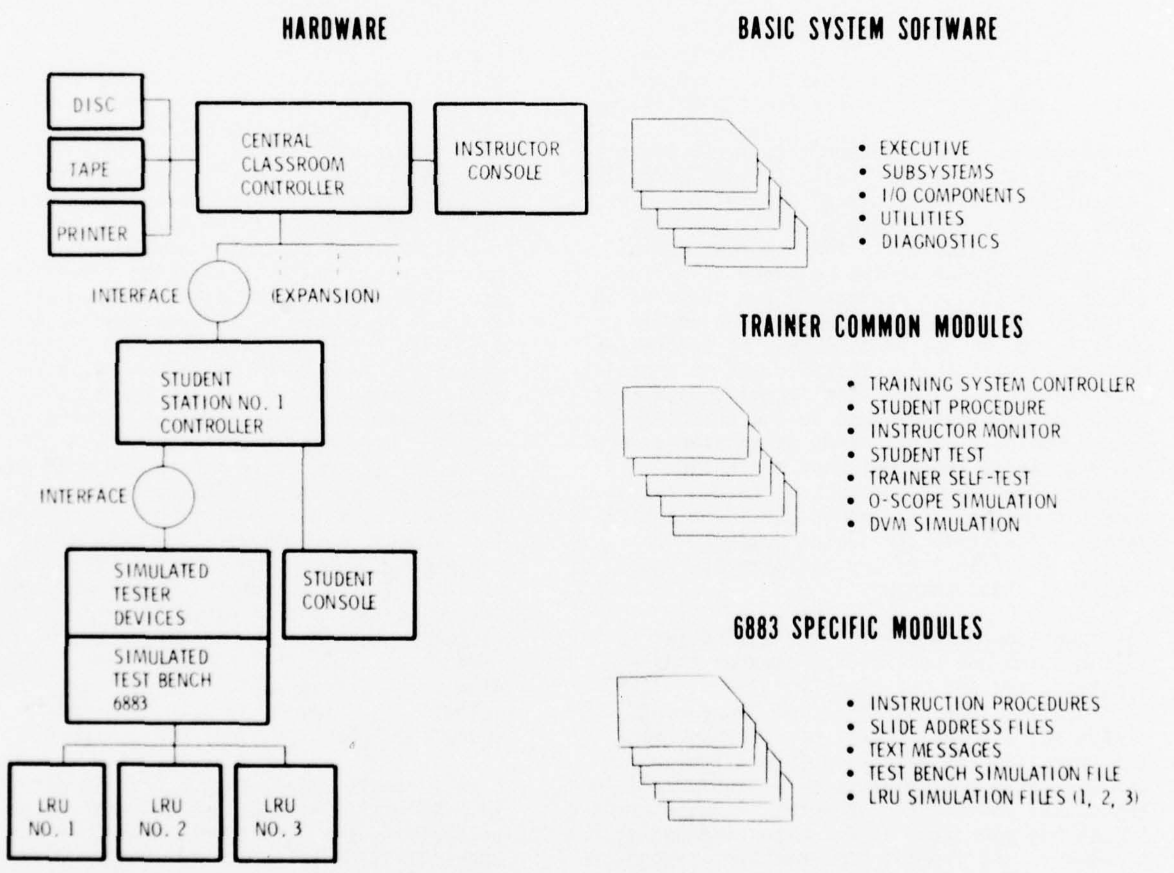

Figure 4. 6883 Simulator System Hardware and Software Modules.

The design of the 6883 Simulator System reflects concern for expandability/flexibility. The 6883 Simulator System is a multicomputer system which drives simulations of the 6883 Test Station and associated LRUs through appropriate interface hardware. Student actions on the simulated equipment are sensed by the computer through the same interfaces. Appropriate student guidance and feedback is provided by a CRT/keyboard and random-access slide projector. Student performance is recorded by the computer system and is output to a cassette tape and high-speed printer for recordkeeping. Figure 4 illustrates the training system hardware block diagram.

A minimum of three additional simulator training devices, different from the 6883 can be driven by the Honeywell 716 computer that is acting as a classroom controller. This feature accommodates the Air Force's long-term need for increasing numbers of simulators to meet their training requirements. Moreover, as the focus of training changes with the evolution of test equipment, the hardware system configuration developed for the 6883 can adapt - requiring only the replacement of obsolete simulation hardware with updated simulations; major system components (e.g., student console, student station controller, interfaces) can be reused with the replacement simulation.

The software and courseware architecture are similarly designed for flexibility (Figure 4). As additional or replacement simulations are incorporated into the system, only the data base modules specific to the new test equipment must be added to the software. Instructional materials or courseware are prepared in a manner that facilitates generation and/or modification of lesson materials by instructor or support personnel. This becomes an especially important feature when reconfiguration of equipment requires changes in the training course content. These kinds of considerations are especially important when designing trainers for developing systems (e.g., F-16). Numerous engineering changes should be anticipated, and a simulator system designed for maximum modifiability can minimize the cost impact of those changes.

Configuration management. The procedures for implementing and controlling changes to the simulator are not yet clearly defined. It is possible that the configuration management (CM) system for simulators will be different from that required for actual equipment trainers. The CM system must process all changes made to the actual equipment, determine if those changes impact the operation and/or effectiveness of the simulator, and process the resultant changes to the simulator software, hardware, courseware, or documentation.

Because the simulator operates in a manner different from the actual equipment and incorporates only a selected subset of all possible hardware features, only a small number of the original changes need be made to the simulator. Changes unique to the training system (e.g., added instructional features) may also require specialized CM procedures to assure that those changes do not cause the simulator to function differently from its operational counterpart, resulting in negative training. It is also unclear if the differences in complexity between the simulator and actual equipment impact the CM procedures required. Further study is needed to define the most cost-effective procedures to employ for simulator configuration management.

The Air Force Human Resources Laboratory (AFHRL) intends to examine alternative CM solutions for the 6883 Simulator System. Hopefully, through their study, a better understanding of the issues will evolve.

SPECIFICATIONS & STANDARDS APPLICATION

A remaining consideration that can significantly impact the cost of fabricating and documenting training systems is the application of accepted military specifications and standards. Indiscriminate application of existing specifications and standards developed for operational equipment, appears unnecessary, costly, and often inappropriate as the training philosophy shifts to replace actual equipment with simulators. Indeed full compliance with these specs and standards nullifies many of the potential benefits of low-fidelity simulation. The 6883 program produced a functional specification that can serve as a model for specifying future simulator-based training systems. Although MIL-STD 490 served as a guideline for organizing the 6883 document, deviations from that prescribed organization were incorporated, where appropriate, to accommodate the trainer-unique material discussed. Likewise, fabrication of the 6883 Simulator System is in accordance with Best Commercial Practices. This permits, for example, using non-ruggedized (and thereby less expensive) computers and simulation equipment. Suspension of the traditional military standards governing equipment fabrication is appropriate given that the simulator system is intended for classroom rather than field use. It will not undergo the routine disassembly, transport, and reassembly (at potentially unfavorable sites) for which operational test stations are designed.

A very recent Department of Defense directive (DOD Directive 4120.21) recognizes the need to reassess the strict enforcement of existing specifications and standards. The revised policy directs the services to establish procedures for the selective application and tailoring of specifications and standards, to impose only "essential system needs," to avoid "blanket contractual imposition," and

to solicit recommendations from prospective contractors. These procedures apply throughout the procurement process; each program is required to document the extent to which specifications, standards, and data item descriptions have been modified.

OPEN QUESTION

Numerous studies (e.g., 11, 12, 13) have concluded that simulators train equally as well as operational equipment alternatives. However, most of these studies have suffered from the lack of adequate measures of transfer of training.

The Air Force Human Resources Laboratory recognizes this deficiency and is initiating a formal program to determine the relative merits of simulator-based training. A formal training-effectiveness analysis of the 6883 system will be conducted by AFHRL to assess the practicality of I-level maintenance simulation. The relative merits of actual equipment-based and simulator-based training will be contrasted through a comparison of students trained using the present operational 6883 Test Station and those trained using the simulator. A range of simulation techniques and training procedures has been specified to permit assessment of the relative effectiveness of different approaches. Detailed performance measures are specified which far exceed the instructor's immediate needs. These data will be recorded on cassette tape for later statistical analysis and can provide insight into both the simulator training effectiveness and the student's learning process. Finally, the hardware design incorporates a number of features which facilitate data collection and system modification. Through the inclusion of such additional hardware, software, and courseware features, an effective evaluation of the feasiblility and practicality of maintenance simulation will be possible.

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REAL-TIME SIMULATION OF JEFF(B) AMPHIBIOUS ASSAULT LANDING CRAFT

DAVID YIH
Naval Training Equipment Center

INTRODUCTION

Two prototype Amphibious Assault Landing Craft (AALC) designated JEFF(A) and JEFF(B) are being developed by Aerojet General Corporation, Tacoma, Washington and Bell Aerospace Company, New Orleans, Louisiana, respectively (figure 1). The craft are designed to ride on air contained by the flexible skirt systems and pressurized to slightly higher than the ambient pressure by the fan systems.

The missions of the craft are to ferry troops and supplies from supply ships to a landing beach and return. The ships are usually cruising off-shore to avoid attack by the shore batteries and surface-to-surface missiles. In performing the missions, the crafts must enter or back out from the well of the supply ships or come alongside the ships for reloading or unloading. The craft must be able to ride on the waves at sea state 2, travel across deep water, shallow water and surf zone, land on a sloping beach, and drive inland. The craft are designed to be able to negotiate approximately 12% slope at 120,000 lbs. normal payload.

This report presents the feasibility study of developing a real-time AALC simulator for JEFF(B) craft covering the over water operation and planning the over land operation.

METHOD OF APPROACH

The JEFF(B) craft has been selected for this study. The reason for selecting the JEFF(B) over the JEFF(A) was that the JEFF(B) had more data available at the time the project was being initiated.

The perturbation method has been extensively used for vehicle simulation. However, the fidelity of using the method to duplicate the AALC behavior is dependent upon the validated data obtained from the scaled model tests. As was pointed out by Doctors and Sharma (Reference 1), the perturbation method using resistance from constant speed towing tank results is not sufficient to predict the maneuvers, particularly involving large acceleration near hump speed. For AALC operation, large variation of acceleration and control forces are anticipated. Furthermore, a small change of the state of the craft may result in highly nonlinear forces and large coupling effects between degrees of freedom. Therefore, applying the perturbation method to simulate an AALC is questionable.

The modeling technique used in the present simulation is quite different from the conventional perturbation method. The mathematical model is based on the nonamnesic and nonlinear concepts. As the test results will show, the success of this model is mostly due to the simulation of the vehicle generated wave (VGW) and air cushion systems. The model was developed by the C.S. Draper Laboratory (References 2 and 3).

MATHEMATICAL MODEL

The mathematical model has six degrees of freedom and consists of five major sections; namely, the equations of motion, effector, engine, air cushion system, vehicle generated wave, and ocean wave systems (figure 2). The terrain model portion will be added later.

Equations of motion

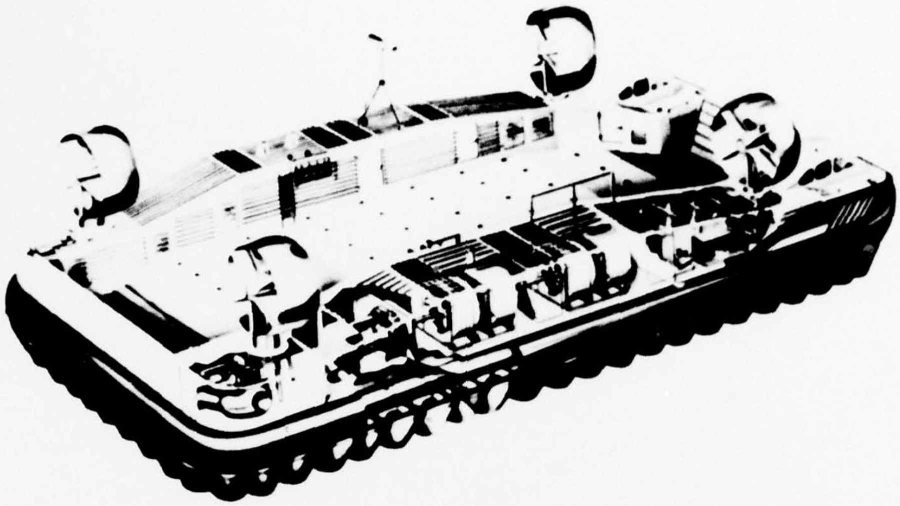
To provide proper motion and visual cues to an operator, the equations of motion are derived with respect to the operator station. The ETA equation is the control equation which is used to calculate the total wave heights for over water operation or the terrain heights for over land operation. However the terrain model is yet to be incorporated in the program. These ETA values are then used to calculate the cushion forces and moments acting upon the craft. Using the ETA equation, there is no need to employ two separate models for amphibious operation. Thus, considerable savings on the development cost of the mathematical model and real-time program have been realized.

Effector and Engine

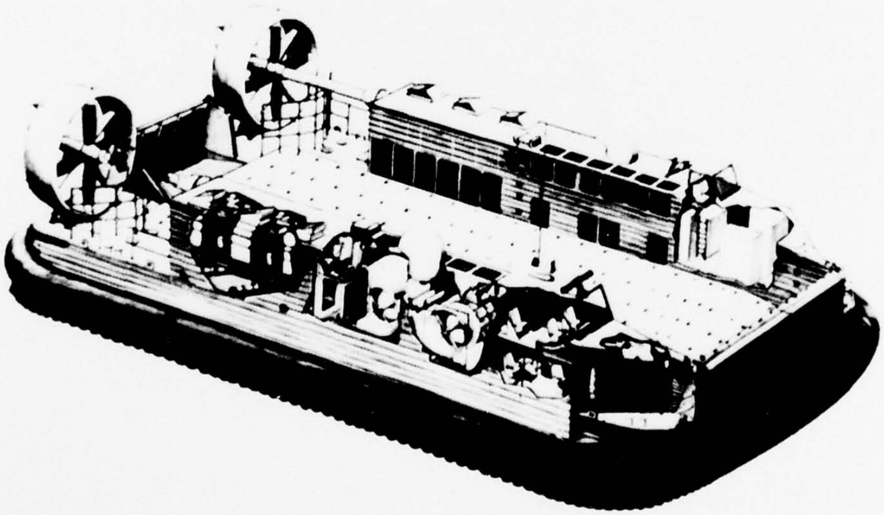
The technique used to model the effector and engine is a conventional one. The data provided by the Bell Aerospace Company for simulating these components are considered to be adequate.

Air Cushion System

The craft is supported by means of the air cushion pressure. Therefore, craft performance is intimately related to the accurate determination of cushion pressure. The cushion model is described by a set of six



JEFF A



JEFF B

Figure 1. Cutaway views and Characteristics of the JEFF Craft

TABLE 1. SELECTED PRINCIPAL CHARACTERISTICS OF THE JEFF CRAFT

	JEFF(A)	JEFF(B)
Overall length on cushion	96'	87'
Overall beam on cushion	48'	47'
Height	23'	23.6'
Design gross weight	340,000 lbs	325,000 lbs
Design payload (overload)	120,000 (150,000)	120,000 (150,000)
Engine	6 Avco Lycoming TF-40 Free Turbine Engine totaled 16,800 hps.	same
Propulsors	4 Reversible Pitch Shrouded Propellers	2 Shrouded Reversible Pitch Propellers 2 Bow Thrusters
Life Fan	8 Single Centrifugal Fans	4 Double Centrifugal Fans
Control system	Fly-by-wire 4 Rotatable Propulsors Yaw rate feedback Auto pilot	same 2 Rotatable Bow Thrusters 2 Aerodynamic Rudders 2 Shrouded Propellers
Skirt system	Looped Pericell 5' height	Bag Finger with Stability Trunks 5' height
Speed (Seastate 2 and 25 knts Headwind)	50 knts	50 knts
Range	200 n. miles	200 n. miles
Maximum slope	11.5%	13%

nonlinear continuity equations which are iteratively solved by a multidimensional Newton-Raphson procedure. Using the modeling technique, this AALC mathematical model does not have explicit damping terms except in yaw. The QPUMP terms in the continuity equations (figure 3) actually provide damping to the craft.

Vehicle Generated Wave and Ocean Wave

The concept of the VGW system is that wave configuration is a function of past velocity history and present state of the craft. Modeling the VGW is the most complex part of the whole simulation. The purpose is to obtain a VGW height under the designated hull point. This is done by integrating from the past T = -t to present T = 0 over 82 values of Kernal function (K).

$$\eta_{VGW} = \int_{-t}^{0} K \, dt$$

A total of 25 points are required. The preparation for the values of the Kernel function is a very tedious work. It took approximately three minutes to compute one Kernel value. A total number of 30 x 30 x 82 values were computed and tabulated in 82 tables which are stored in an equal time interval. The VGW profile under the hover condition is shown in figures 4 and 5.

The seawave simulation is a sinusoidal wave system. It takes in one dominant frequency at a time. It is desirable that it be replaced by a random wave system for more realistic simulation.

The off-shore wave system represents the waves propagating from deep water, through shallow water, and surf zone to a beach. The wave model is based on the small amplitude wave theory with the Stokes second order correction for the wave profile. The basic characteristics of the off-shore wave system are shown in figure 6.

Terrain Model

When the craft is detected to be on a beach or land, the terrain heights will be calculated instead of the wave heights. The designed terrain heights must be measured with respect to the main reference level as illustrated in figures 7, 8, and 9.

REAL-TIME PROGRAMMING

The real-time program is organized into five major modular sections (figure 10). These are:

- Program load and initiation
- Background
- Foreground
- Trap handling
- Common storage

To start an experimental run, the AALC program and VGW tables are loaded from separate magnetic tapes with all interrupts inhibited. The traps are initialized. If the program is successfully loaded, the program entry INITSTRT initializes the I/O and the timing and transfers to the background tasks. The VGW height profile calculation is performed in the background. The background tasks take up all computer time not spent in the foreground. The tasks of foreground operation are to provide the proper time interval for AALC mathematical model of the real-time operation. There are three program modes of operation, namely hold, reset, and operate modes. The operate mode is the real-time simulation of AALC model. The vehicle is maneuverable in this mode. The traps handle the abnormal or error conditions of the software and hardware. The common storage acts as a data pool for the program.

Program Description

The mathematical model is implemented on the Sigma 7 digital computer of Naval Training Equipment Center's (NAVTRAEQUIPCEN) TRADEC flight simulator. The program is written in assembly language and floating point arithmetic is used. The program consists of approximately 16,000, 32-bit words and is iterated at 20 cycles per second or 50 milliseconds per cycle. The computer 48 K memory is fully occupied by the instructions and mostly by the data of the VGW. For worst-case operation, 50, 34, and 16 percent of the 50 milliseconds are spent in running the main program, off-shore wave and VGW system, respectively.

EXPERIMENTAL SYSTEM SETUP

The system designated L (figure 11) is incorporated with a Computer Line Drawing Display Unit manufactured by Evans and Sutherland Computer Corporation, Salt Lake City, Utah. The system designated W (figure 12) is incorporated with a Wide-Angle Visual System. These visual systems are available in the NAVTRAEQUIPCEN laboratories. Because of the limited fundings, existing equipments have been utilized. The purpose is to demonstrate the feasibility of using these visual systems for the AALC experimental training device.

System L

The Computer Line Drawing Display unit interfaces with the Sigma 7 computer by a subroutine of approximately 500 instructions. Once the unit is started, it operates independently, fetches the data and drawing instructions from the computer memory, and continuously draws the well of the LHA mother ship.

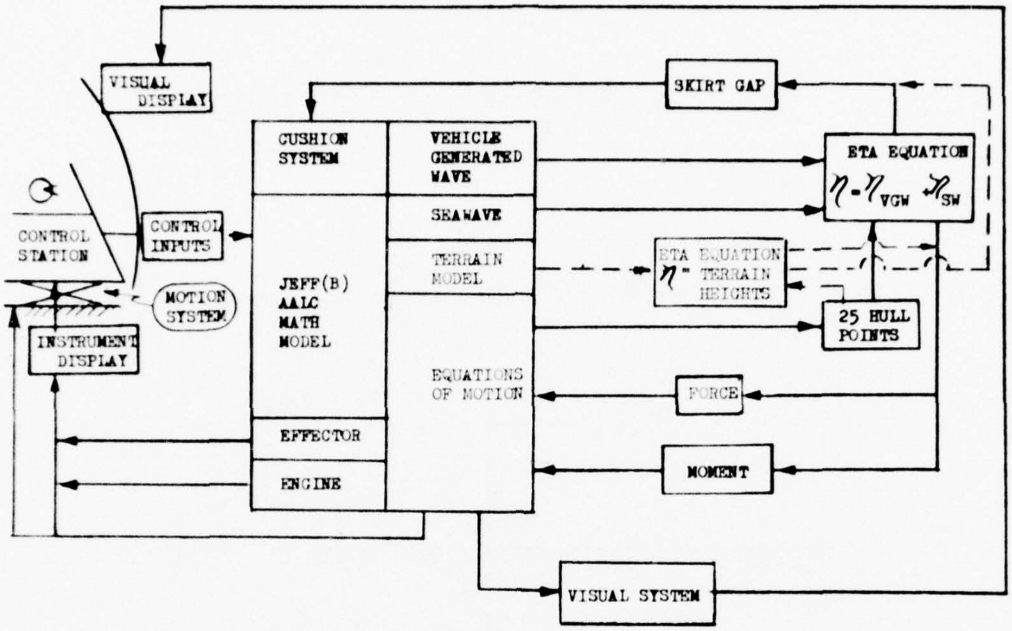


Figure 2. System Diagram for Amphibious Operation

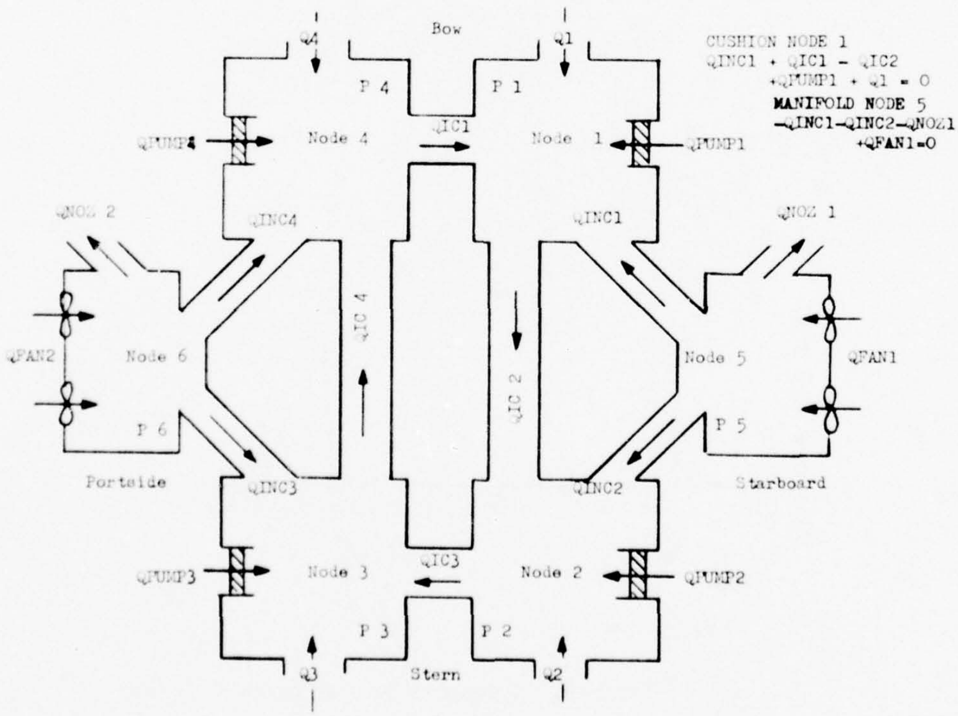


Figure 3. Cushion Pressure Schematic

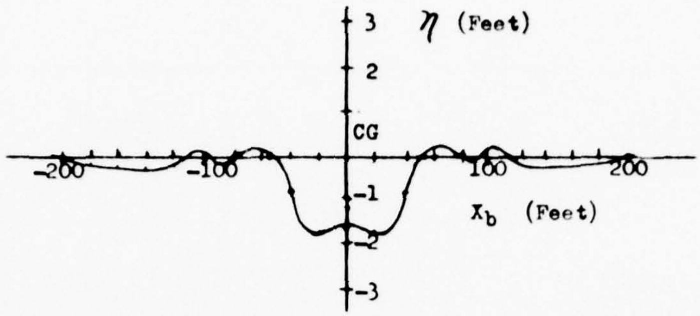


Figure 4. VGW Profile u = 0, Longitudinal

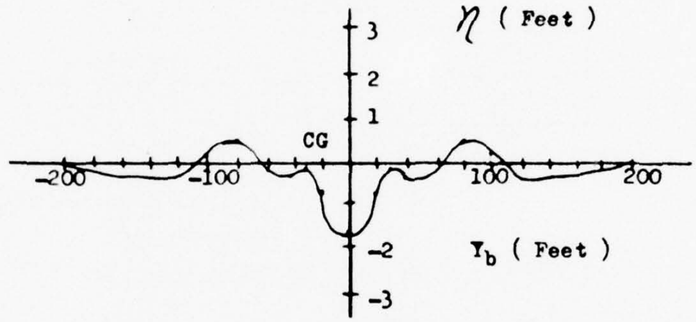


Figure 5. VGW Profile u = 0, Lateral

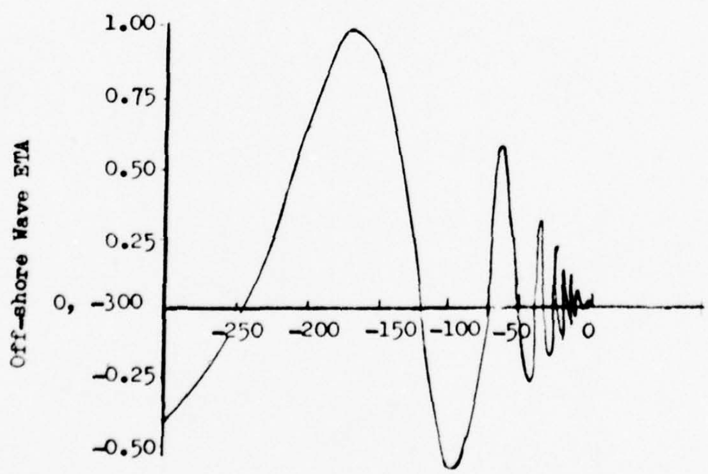


Figure 6. Off-shore Wave at Beach

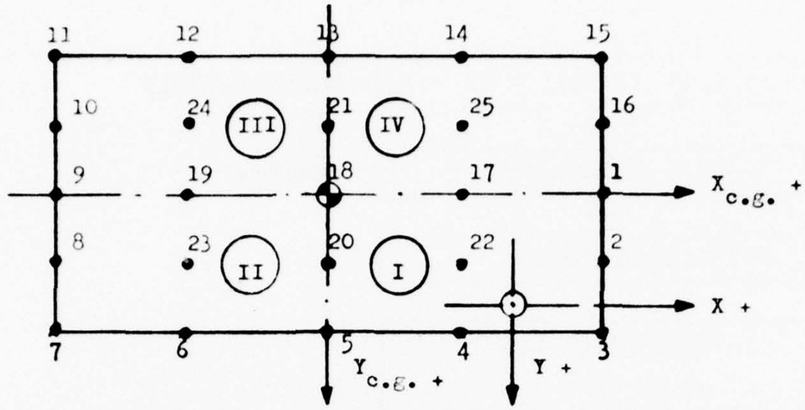


Figure 7. Location of 25 Hull Point

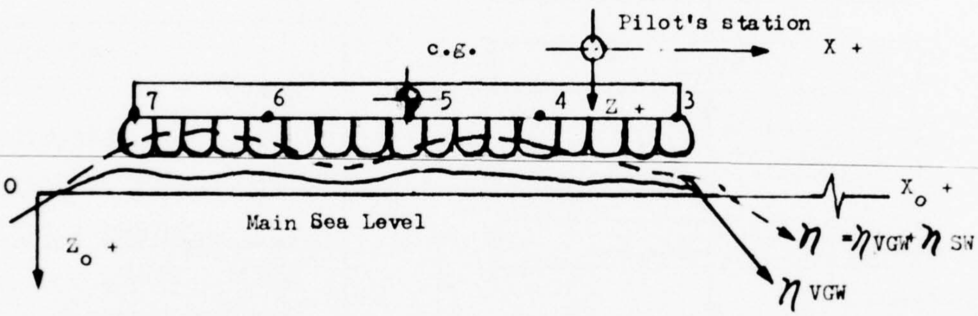


Figure 8. Wave Amplitude Schematic

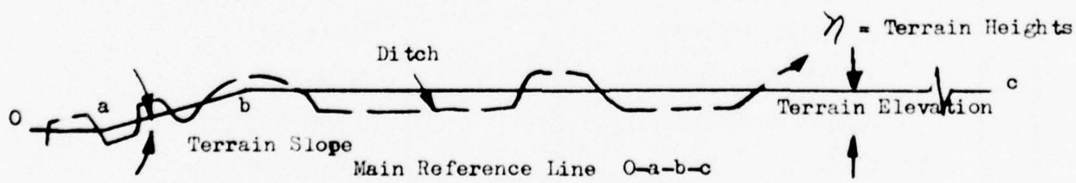


Figure 9. Terrain Height Schematic

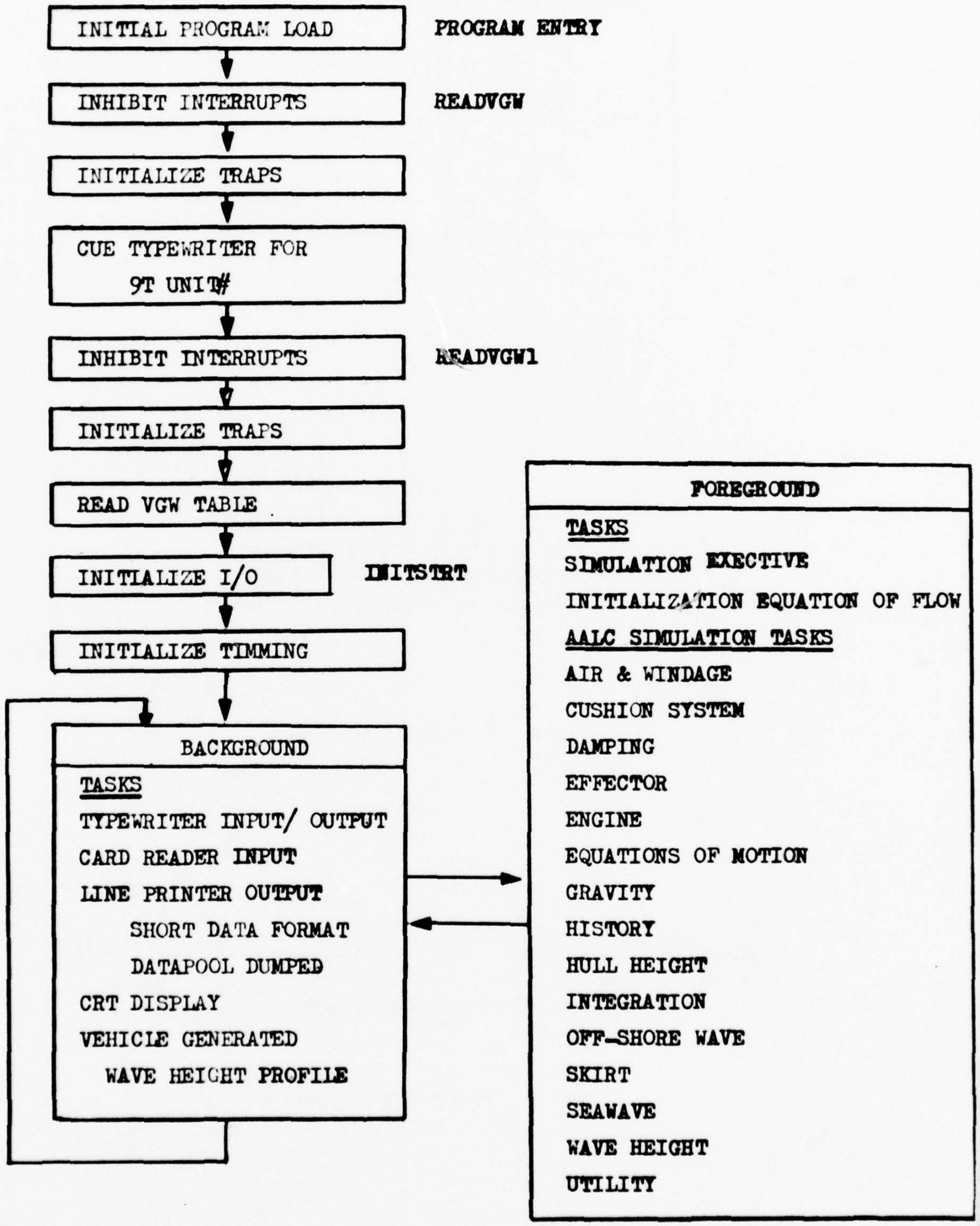


Figure 10. Basic Software Flow and Structure

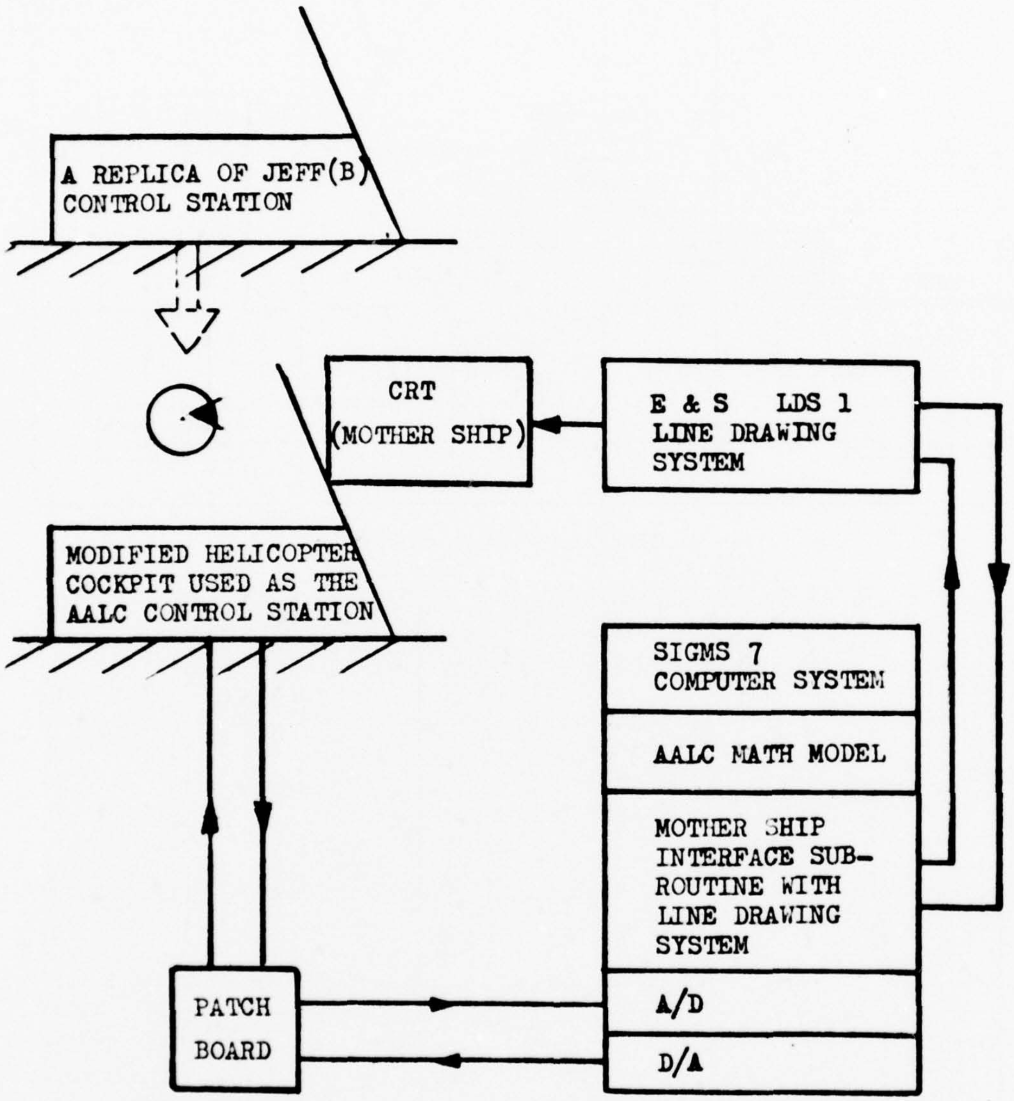


Figure 11. System with Line Drawing Display

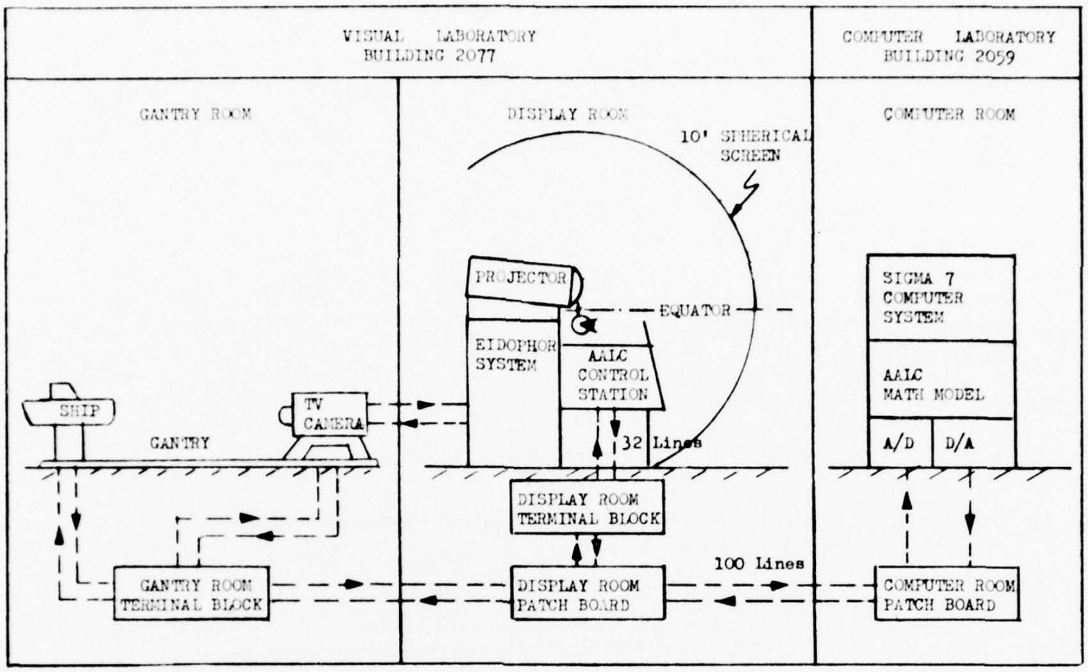


Figure 12. System with Wide Angle Visual Unit

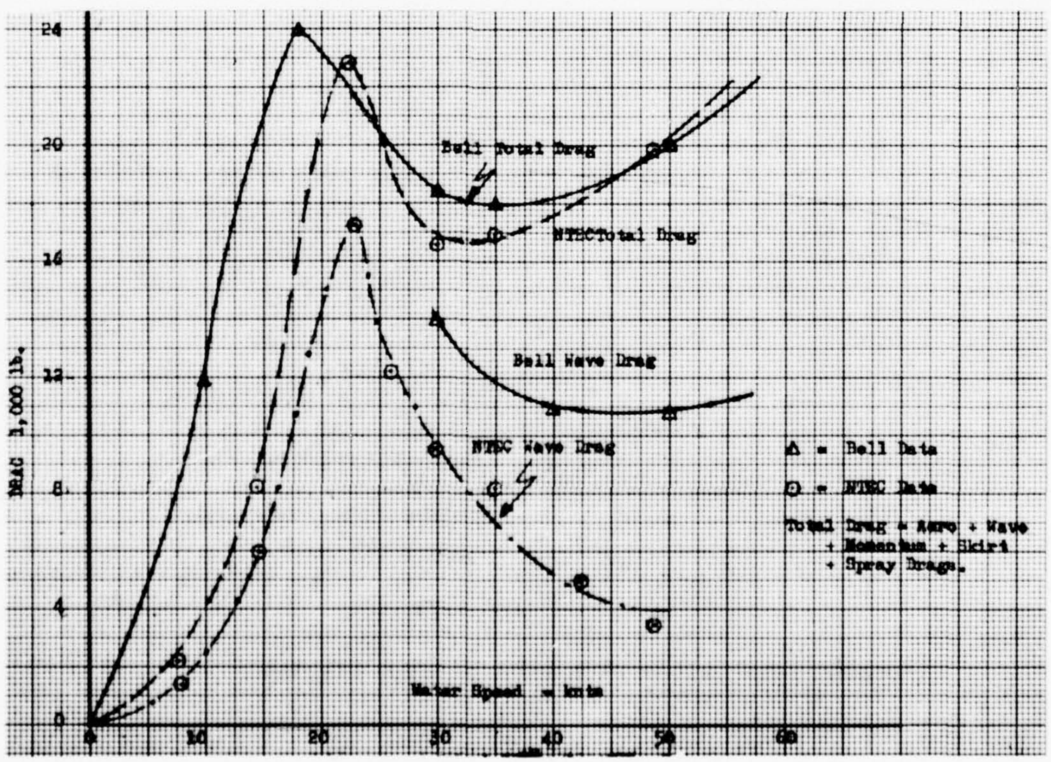


Figure 13. JEFF(B) Drag Characteristics

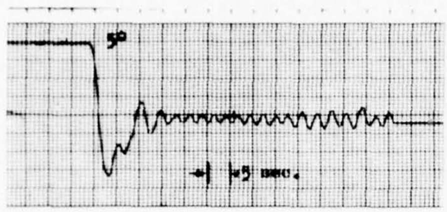


Figure 14.1. Pitch Frequency Response with VGW 5° Impulse, U = 0

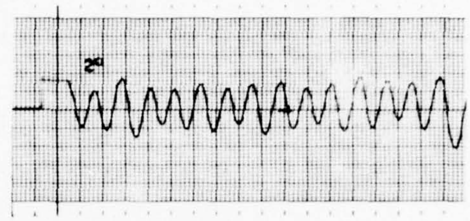


Figure 14.3. Roll Frequency Response with VGW 2° Impulse, U = 0

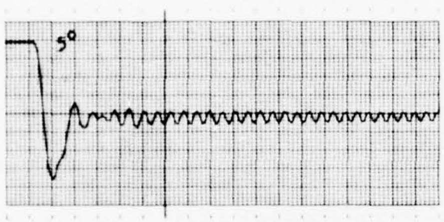


Figure 14.2. Pitch Frequency Response with VGW 5° Impulse, U - 50 knots

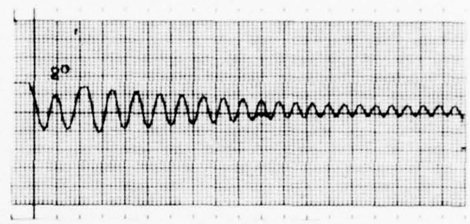


Figure 14.4. Roll Frequency Response with VGW 2° Impulse, U = 50 knots

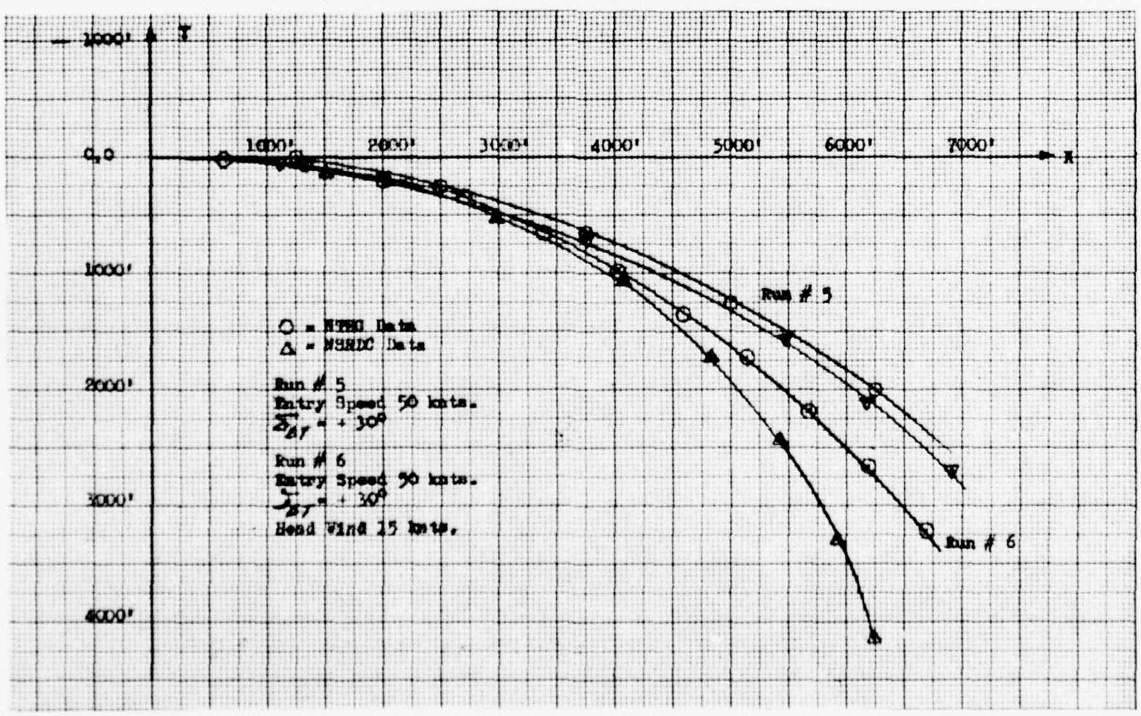


Figure 15. Turning Maneuver from a 15 Knot Headwind

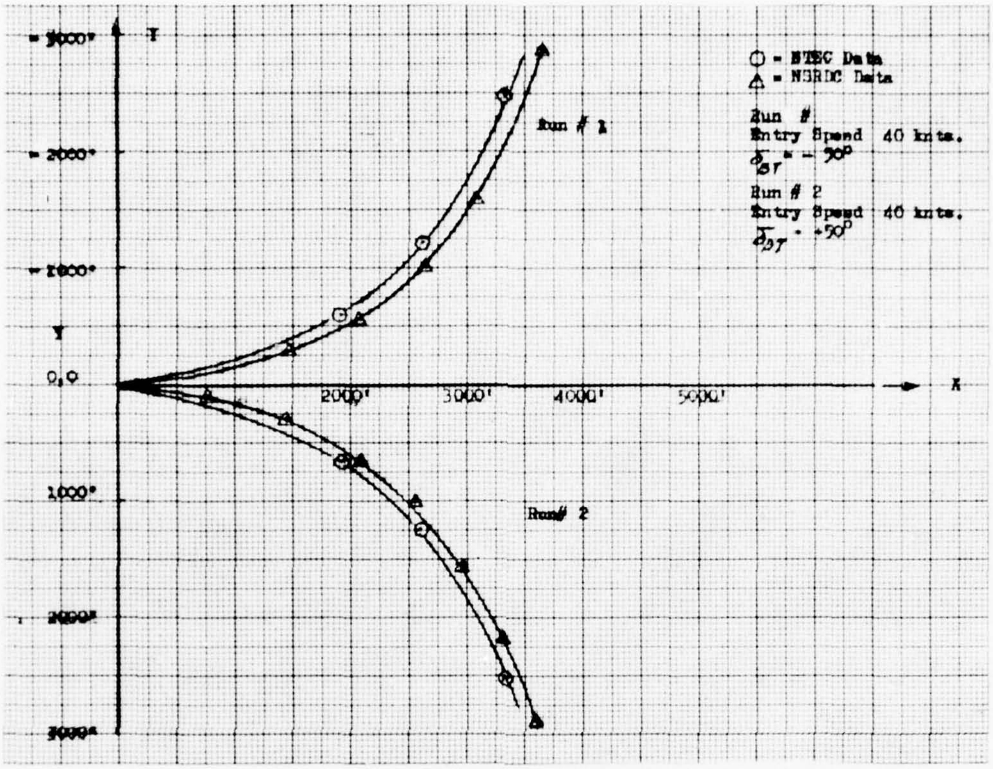


Figure 16. Steady State Turn

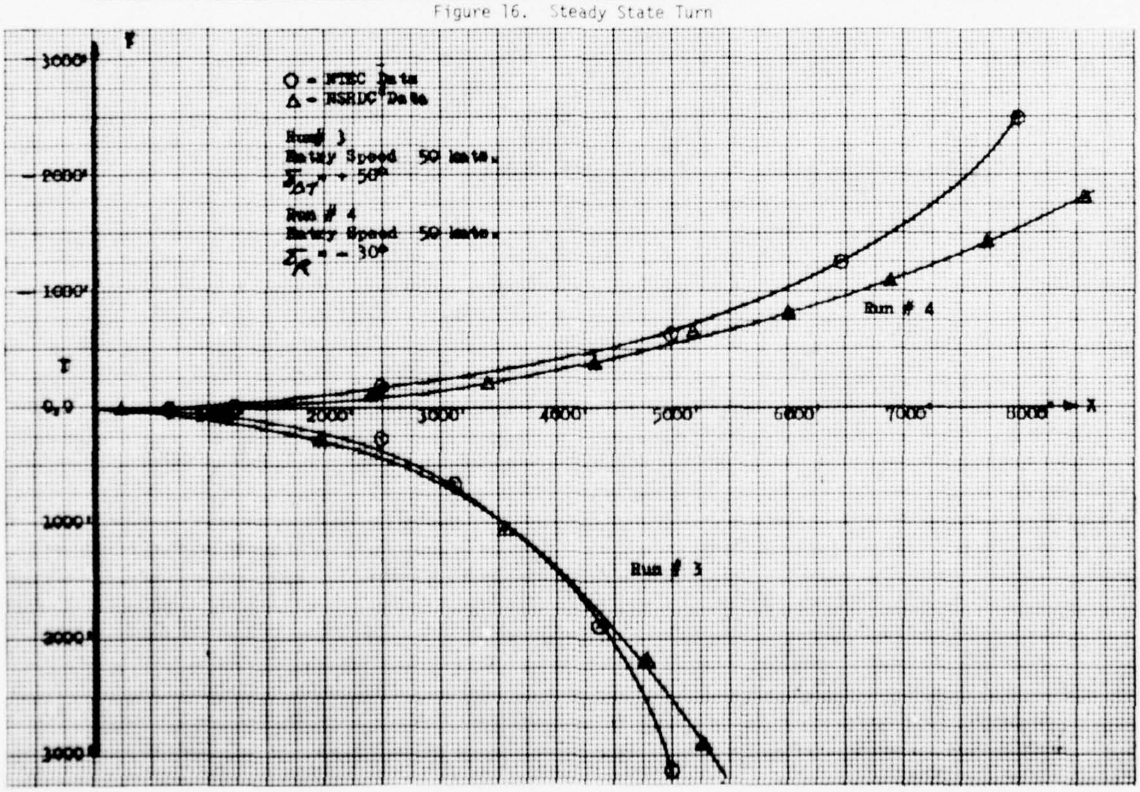


Figure 17. Steady State Turn

The AALC attitude instructions are stored in the computer memory by the program of AALC mathematical model and are updated every program cycle. The function of the display unit is to continuously draw the well of a LHA mother ship being viewed from an AALC operator's station during the docking maneuvers.

The system L integrating the modified and instrumented helicopter cockpit, digital program, and the Computer Line Drawing Display unit has been used to obtain performance data on the simulation and allow operators to perform docking maneuvers.

System W

The existing NAVTRAEQUIPCEN Wide-Angle Visual System is a single channel TV system with a field of view of 60^0 vertical and 160^0 horizontal using TV camera and an Eidophor light valve projector. The camera and projector are 1023-line units.

The system W integrating the replica of JEFF(B) control station, digital program, Wide-Angle Visual system, gantry system, 1/50 scaled LPD model, and 10-ft radius spheric dome is being used as an experimental training device. The camera picks up and processes the image of the physical model of LPD and puts out signals to the Eidophor unit. It processes signals and projects the image of the LPD model on a spheric screen supported by the structure of the spheric dome. The picture displayed on the screen with brightness of 5-foot lambert provides the visual scene to the operator. The movement of the gantry upon which the camera is seated is driven by the outputs of navigational positions and heading from the computer program which is governed by the operator's commands issued from the control station. It is instrumented the same as System L. Because of the limitation of the gaming area, the system is exclusively used for the docking maneuvers. No attempt has been made to collect performance data from the system.

Plan for Over Land Operation

The mathematical model has been developed for amphibious operation. The current model can operate on a flat ground. The plan is to add the terrain model to the program. The data base will be designed. No sophisticated equipments are required.

Test Result

Data dealing with the over water maneuvers were collected using System L. A total of five runs were conducted to verify the basic characteristics of the mathematical model. The VGW profile at hover condition, off-shore wave, hump speed and frequency response are presented in figures 4, 5, 6, 13, and 14, respectively. A total of eight runs were conducted at various entry speeds and control settings. The collected performance data were compared with the data provided by NSRDC from a nonreal-time JEFF(B) simulation program. The data are presented in figures 15, 16, and 17. The correlation between two sets of data were satisfactory. During August 1976, a total of 30 runs were conducted by Mr. James Fein of NSRDC to verify the performance of the craft over calm water and over wave. Most of the runs were conducted at the entry speed of 50 knots and at various control settings. Zero and high-speed (over hump speed) turnings were performed. The tests were conducted over wave at various wave heights (1' and 3') and periods (5, 6, 7, and 7.5 seconds). The performance data were rated satisfactory.

After completing the docking maneuvers in the System W on 28 February 1977, Lt. J.N. Mullican and Mr. R.E. Hughes of Amphibious Assault Landing Craft Experimental Trials have made comments on the operation of the experimental design. This points out a need for further refinement of the mathematical model.

Conclusion

System L has fulfilled its assigned objective. The existing Computer Line Drawing Display unit has been utilized to provide the interim solution to the docking maneuvers. The mathematical model was tentatively validated by comparing our collected performance data with the data provided by NSRDC's nonreal-time AALC program. The final validation of the mathematical model will be made when the full trial data or data from 1/6 radio controlled model comes available.

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A LOW-COST VISUAL SENSOR SIMULATOR

DR. WILLIAM McCORMICK, RICHARD KINNEY AND WALTER MASON
Technology Incorporated
and
DR. TONY DeTHOMAS
Air Force Flight Dynamics Laboratory
Wright-Patterson Air Force Base

INTRODUCTION

Pilot acceptance studies of Digital Avionics Information System (DAIS) concepts, conducted by the Air Force Flight Dynamics Laboratory, required cockpit presentation of typical forward looking sensor imagery. The objectives of the studies were to verify that the DAIS concepts do not jeopardize safety-of-flight integrity, measurably degrade performance of flight control configurations, nor degrade the pilot effectiveness. At the same time, the resulting system must not only be usable but be fully acceptable to the pilot. The AF Flight Dynamics Laboratory DAIS Simulation Facility was developed to accomplish these objectives through subject testing, using a replication of a Close Air Support aircraft cockpit. The program plan for the DAIS Simulation Facility includes both a stand alone capability and integration with the FDL Terrain Board Facility which will provide a projected televised view of the simulated flight path terrain for direct pilot viewing through the cockpit window. To enhance the realism of the cockpit environment, typical visual sensor imagery was required which would be representative of forward looking radar, low-light-level television and forward looking infrared sensors, corresponding, in real-time, to the projected scene. A Visual Sensor Simulator, described in the following sections, was developed by Technology Incorporated to provide a low-cost solution to this requirement. By processing the terrain board video signal in real-time through the use of analog circuit techniques, simulated radar and electro-optical sensor imagery was generated which has been highly acceptable to experienced pilots.

The Visual Sensor Simulator was designed to present representative imagery and not actual target signatures. The design study was based on various target signature data but the correlation of sensor return for comparison of target signatures was not included in the initial program plan. Future studies are planned to investigate these requirements in conjunction with other programs.

DESIGN CONSIDERATIONS

The present version of the Visual Sensor Simulator was designed to be operated with a direct terrain board video signal, although other input signals are feasible. A generalized application is shown in Figure 1, where the primary electrical signal is provided by a TV vidicon that is responding to a visual scene generated either from a terrain board, a motion picture, or a video tape recording. The sensors considered in this discussion will be forward looking IR (FLIR), forward looking, real-aperture radar (FLR), low-light-level TV (LLLTV), and synthetic aperture radar (SAR).

Any realistic sensor simulation should approximate those sensor parameters that are of significance to the human observer. In Figure 2 a general sensor configuration is presented, including the elements of scene definition, atmospheric effects, and specific sensor characteristics. Scene definition includes the significant parameters (e.g., resolution, reflectivity $R(\lambda)$, emissivity $\epsilon(\lambda)$, thermal inertia, object contrast) that are of importance within the spectral region of the sensor; atmospheric effects include all noise and spectral dependent attenuation effects; finally, the sensor itself is defined as a complicated function of S/N ratio, modulation transfer function $M(f)$, signal compression, and various other special sensor effects. Consistent with the sensor model of Figure 2, each of the four sensors will be defined in terms of operating S/N, modulation transfer function, signal compression properties, and relevant special effects. Referring to Figures 1 and 2, the primary analog sensor-simulator input is, in all cases, generated from a vidicon and is, therefore, restricted to target reflectivity properties, $R(\lambda)$, in the visual spectral region; any useful simulator, whether analog or digital, must make a correlation between the visible $R(\lambda)$ and those target properties relevant to the particular sensor (e.g., $\epsilon(\lambda,T)$ for FLIR and $R(\lambda)$ in the microwave region for FLR).

ANALOG CIRCUIT TECHNIQUES

For the cockpit simulator application, it is assumed that the primary TV signal will be initially noise-free ($S/N = \infty$) and that the raster scan pattern will be roughly 600 lines, 30 frames/sec or equivalently 5 MHz in video bandwidth.

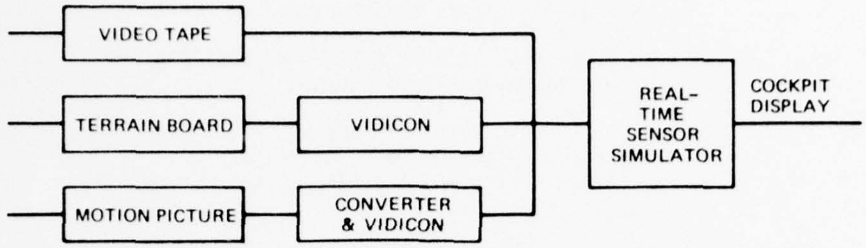

Figure 1. Sensor Simulation Application

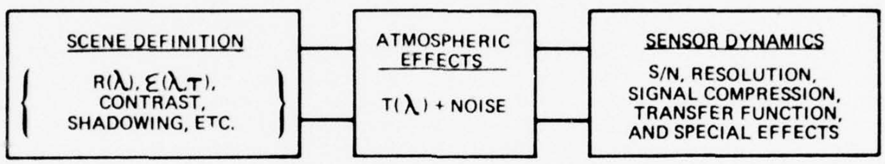

Figure 2. Sensor Modeling

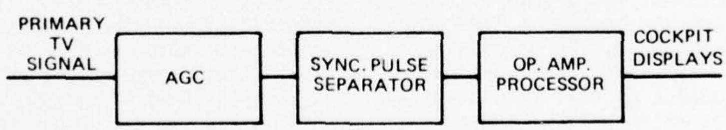

Figure 3. General Single-Channel Processor

Analog circuit components process each TV raster line sequentially with the processing performed by a cascade of high performance, operational amplifier-based processing elements. Utilization of OP-AMP processing at video bandwidths is made possible by the recent availability of wide-band, high slew-rate operational amplifiers. Figure 3 illustrates the general single-channel processor where the heart of the processor is the "OP-AMP" processor unit henceforth referred to as "the single-channel processor." The single-channel processor begins with an OP-AMP signal-plus-noise summation where the raster signal format is added to a flat spectrum, level-controlled noise source as shown in Figure 4. The next stage is the edge enhancer which is essentially a differentiator and is used to simulate "hot spots" in FLIR and specular returns in both FLR and SAR coherent radars. The next processing unit simulates the overall linear sensor transfer function, M(f), by means of a flexible, active filter. The final processing unit is usually a zero-memory nonlinearity (ZMN) designed to simulate signal blooming, gray-level compression and target $R(\lambda)$, $\varepsilon(\lambda,T)$ effects; ideally, the ZMN unit should have independently set slopes and breakpoints as illustrated in Figure 5.

Utilizing wideband operational amplifiers, acceptable simulations for the sensors were achieved by using the "single-channel processor" described above in a breadboard version. For the second generation simulator, a "two-channel processor" capable of selectively processing targets and background was developed. In order to implement this two-channel processor, it is necessary to detect targets in real-time and, with proper time phasing, switch between a target processor and a background processor. Because all useful target signatures require the entire target history (e.g., width between sharp edges, magnitude, target modulation, etc.), the principal signal path of the two-channel processor must be delayed by some fixed amount (Figure 6) while the target/background decision is being made. Fortunately, low distortion, video time delays are now available in the 0 to 10 microsecond range. The target detection circuit and related timing circuits are entirely digital and control high-speed CMOS analog switches with switching times on the order of 10-20 nanoseconds.

SENSOR CHARACTERISTICS

Despite the generality of the one- and two-channel processors, the specific features of the individual sensors must be considered in any useful analog sensor simulation. The following exposition is a sensor-by-sensor discussion of how each sensor is simulated using the analog approach.

Forward Looking Infrared (FLIR)

The major challenge for an analog FLIR simulation is the accurate modeling of scene thermal emissivity. A truly accurate TV-derived FLIR simulation must somehow relate visual reflectivity to IR emissivity, and in addition, account for thermal inertia effects. Analytically, the TV terrain responses can be expressed in integral form as:

$$I_{TV} = k_{TV} \int_{\lambda_3}^{\lambda_4} R(\lambda)\, C(\lambda)\, d\lambda$$

where the limits, λ_3 and λ_4, represent the visual wavelength region for TV response, $C(\lambda)$ is the atmospheric transmittance, and k is a constant, including illumination, etc. The corresponding FLIR output can be expressed as:

$$I_{FLIR} = k_{FLIR} \int_{\lambda_1}^{\lambda_2} \varepsilon(\lambda)\, C(\lambda)\, B(\lambda,T)\, d\lambda$$

where $\lambda_1 < \lambda_2 < \lambda_3 < \lambda_4$.

Despite the difficult thermal inertia problem, a relationship does exist between $\varepsilon(\lambda)$ and $R(\lambda)$ in the form of Kirchoff's law; namely, that $\varepsilon(\lambda) + R(\lambda) = 1$ or that emissivity and reflectivity sum to unity. While this relationship does not directly solve the problem, inasmuch as the visual and IR wavelength regions are different, it does indicate that bright TV areas will in general be dark in the IR image. Given this somewhat "loose" situation, a reasonable approach is a two-channel configuration where the respective ZMN's are calibrated according to the ensemble averages of the target/background emissivities. Since the ZMN's are easily altered by pot adjustments, experience can be quickly gained from calibrating real-life TV, FLIR runs.

Another characteristic feature of FLIR imagery is the presence of "hot spots" on man-made targets, e.g., tanks and trucks. One possible method of simulating the "hot spot" is to edge-enhance the characteristic sharp edges of the manmade object and then limit the output of the enhancer with a zero-memory nonlinearity. With a raster scan pattern of variable orientation, a very realistic simulation of the "hot spot" feature can be achieved.

Additional features of an analog FLIR simulation are the "white-hot," "black-hot" options which can be easily simulated using a simple inverting amplifier and also the presence of the faint raster scan pattern

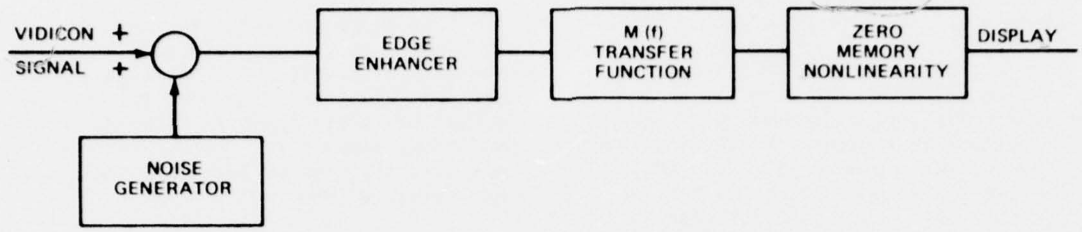

Figure 4. Single-Channel Processor

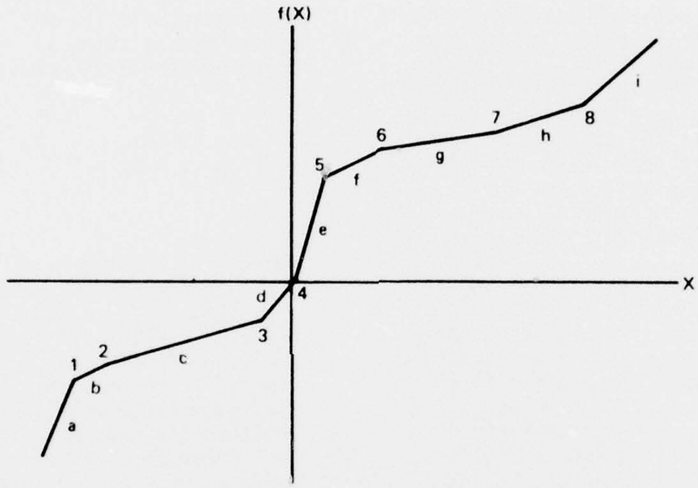

Figure 5. Ideal Zero-Memory Nonlinearity

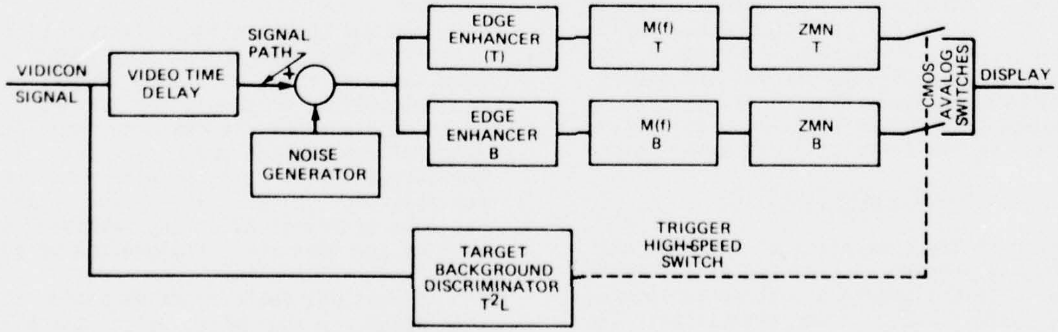

Figure 6. Two-Channel Processor

(nonuniform IR detector mosaic) which can be simulated using a special-purpose circuit synchronized with the vertical and horizontal sync pulses.

The specific two-channel FLIR configuration is shown in Figure 7. It is observed that the edge enhancer is eliminated from the background channel in order to avoid producing an unnatural appearing "sharpness" in the background.

Low-Light-Level Television (LLLTV)

Because the LLLTV sensor responds to the same $R(\lambda)$ as the vidicon, no distinction need be made in the processor between target and background classes. As a result, the preferred simulator configuration for LLLTV is the single-channel configuration. For the analog simulator, the LLLTV features of special interest are signal "blooming" and the image-lag effect. Since signal "blooming" is a result of saturation in the final display stage, the "saturation" ZMN in the LLLTV simulator must be positioned at the last stage after the noise has been added and the signal has been processed through the linear transfer function. The linear transfer function itself will be a cascaded pair of linear operations, the first of which is the time invariant modulation transfer function, $M(f)$, and the second of which is the velocity dependent image-lag operation. The image-lag operation will have an impulse response given in Figure 8 and will be realized with a wideband video delay line as shown in Figure 9.

The overall single-channel LLLTV simulation is presented in Figure 10.

Forward Looking Radar (FLR)

In a typical real aperture PPI display the targets are "blips" against a dark background and are narrow in the range direction but wide (beamwidth times range) in the azimuth direction. Although the PPI display is clearly the appropriate display for a polar coordinate-based system, any coordinate transformation from the rectangular coordinate, as raster scan to the PPI, is virtually impossible for an analog system without scan-to-scan memory. Fortunately, at the longer slant ranges, where the cueing operation is desired, slant range is about the same over the entire ground patch and the coordinate problem is no longer present, permitting the direct use of a rectangular scanned CRT display. The broad flow of a two-channel FLR simulator is to selectively process the target/background classes on the basis of their ensemble averaged reflectivity coefficients, $R(\lambda)$, in the microwave region, incorporating through an edge-enhancer the important specular return nature of the target class. Both target and background signals will be summed and then fed into a video comparator to provide the "on-off," "blip" character of the signal returns. The elongation in the azimuth direction can be readily simulated with a circulating delay line, and the "painting" effect of the scanning physical antenna will be simulated with a special-purpose circuit synchronized to the horizontal and vertical sync signals. Figure 11 illustrates the two-channel FLR simulator.

Synthetic Aperture Radar (SAR)

A synthetic aperture radar simulation was not included in the final system implementation of the Visual Sensor Simulator. However, the basic circuitry design was considered as described below.

As with the FLR sensor, a two-channel SAR configuration would simulate the microwave scene reflectivity, $R(\lambda)$, with dedicated target and background ZMN's. Edge enhancers would simulate both the specular nature of the scene and the overall effect of shadowing (the edge-enhanced simulation of shadowing is quite effective provided the enhancer has a damped oscillatory (zero crossing) step response). Figure 12 demonstrates a typical SAR configuration where the final $M(f)$ simulates the IF pass-band, resulting in a lowering of the overall sensor resolution.

CIRCUIT FUNCTIONS

The hardware implementation of the Visual Sensor Simulator consolidated the desired circuit functions, system interfaces, and controls into the physical package shown in Figure 13.

The desired circuit functions, illustrated in the block diagram (Figure 14), are accomplished by utilizing medium speed T^2L, CMOS logic families and high-speed analog devices. Wherever practical, separate circuit cards were utilized for each type of sensor video, processors to provide independent adjustment and modification capability. Certain common functions, such as power, sync and noise generation which are utilized in all sensor video channels, are provided from dedicated circuit cards. Extensive bypassing and decoupling is utilized on the power supply lines to prevent instability and other anomalies which might result in degradation of the Visual Sensor Simulator performance.

The entire simulator is housed within a standard 19-inch rack and powered by 120 VAC single-phase 60 Hz power. Computer control is provided by optically isolated binary address lines. The computer interface was specially designed to provide a switchable video output capability. The interface circuit provides binary decoding and the necessary video and sync switching.

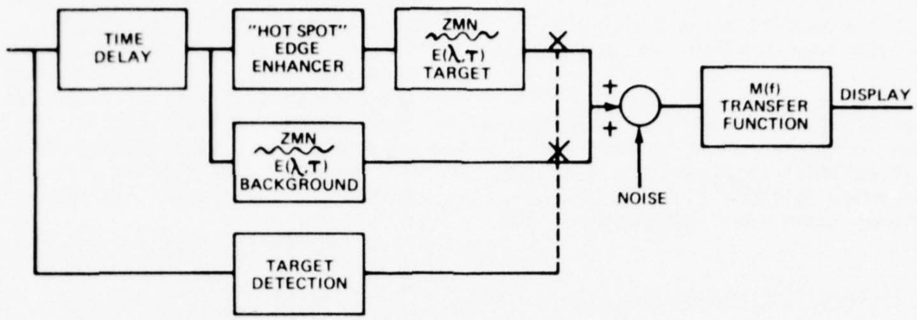

Figure 7. Two-Channel FLIR Simulator

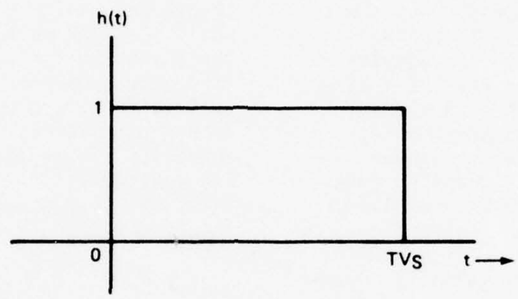

Figure 8. Impulse Response of Image-Lag Simulator

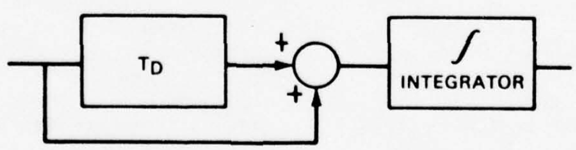

Figure 9. Image Smear Circuit Realization

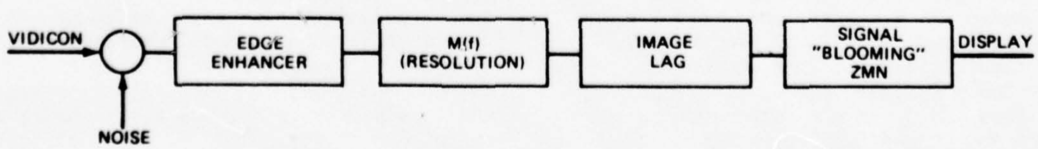

Figure 10. Single-Channel LLLTV Configuration

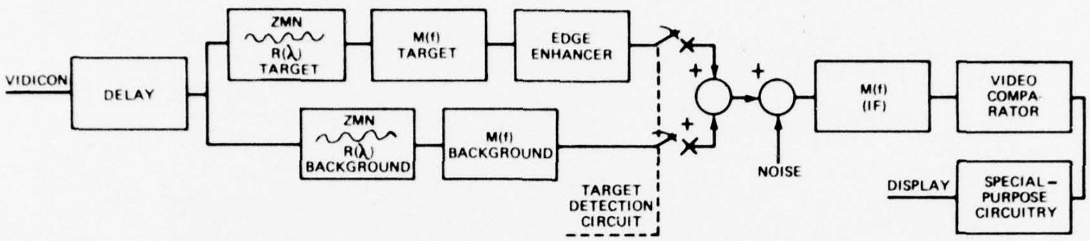

Figure 11. Two-Channel FLR Configuration

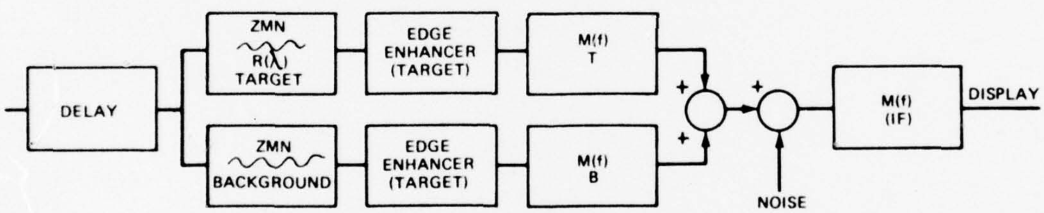

Figure 12. SAR Configuration

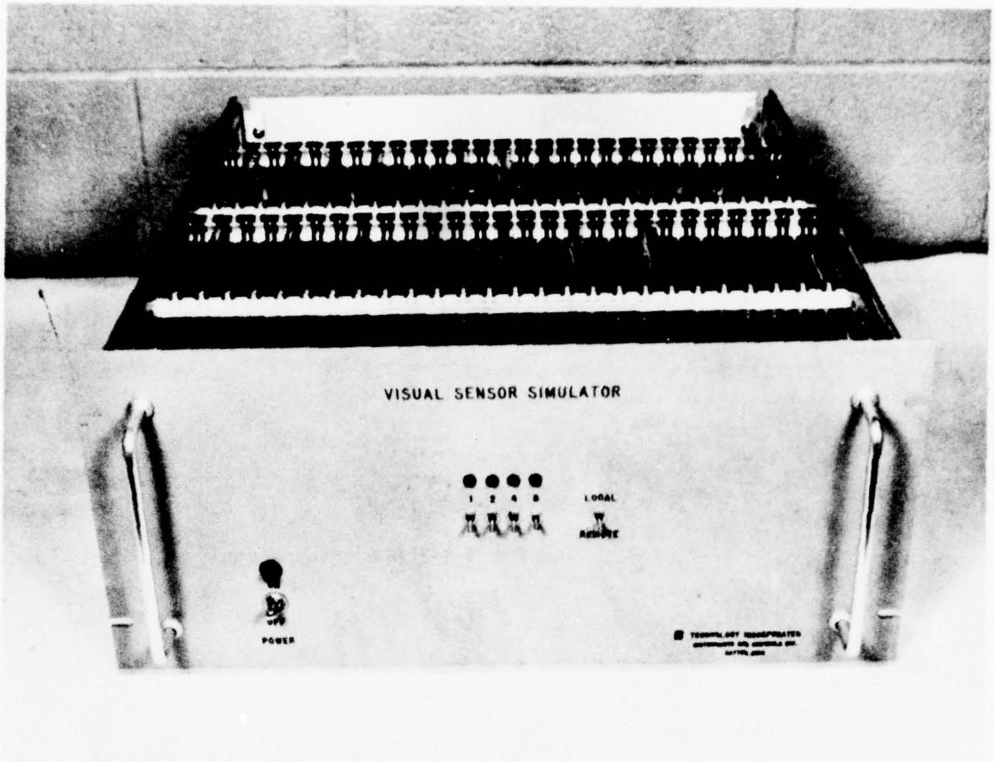

Figure 13. Visual Sensor Simulator

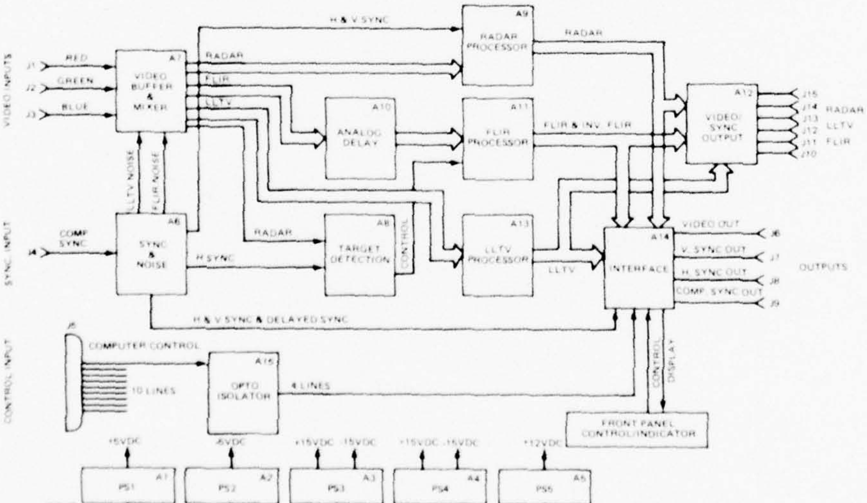

Figure 14. Visual Sensor Simulator Block Diagram

The video input circuitry is designed to accept nominal 1-volt peak, positive-going video for operation on J1, J2 and J3. For operation with RGB color video, all three input connectors are utilized.

The video input impedance is 75 ohms, but can be reconfigured to higher impedance by removal of input termination resistors on the video buffer card A7. If operation is desired on a black and white input video, the use of input connector J1 is recommended.

The sync input is designed to provide for operation with composite negative-going sync pulses (standard). The sync format may be either 525/60 (EIA Standard RS170) or 625/50 ("European Standard"). The negative-going sync input should be between 0.1 volts and 5.0 volts peak amplitude for proper operation. Operation from composite video is possible if adjustment of the sync offset control, A6R2, is performed.

Video and sync ouputs are all capable of driving a 50 foot length of 75 ohm coax cable correctly terminated at 1.0 volt video level with less than 10 percent amplitude roll-off measured at 1 MHz. Each video output has a dedicated video buffer amplifier.

Figure 15 presents an example of the representative imagery generated by the Visual Sensor Simulator. The center photo shows the original scene with the various sensor simulations shown in the surrounding photos.

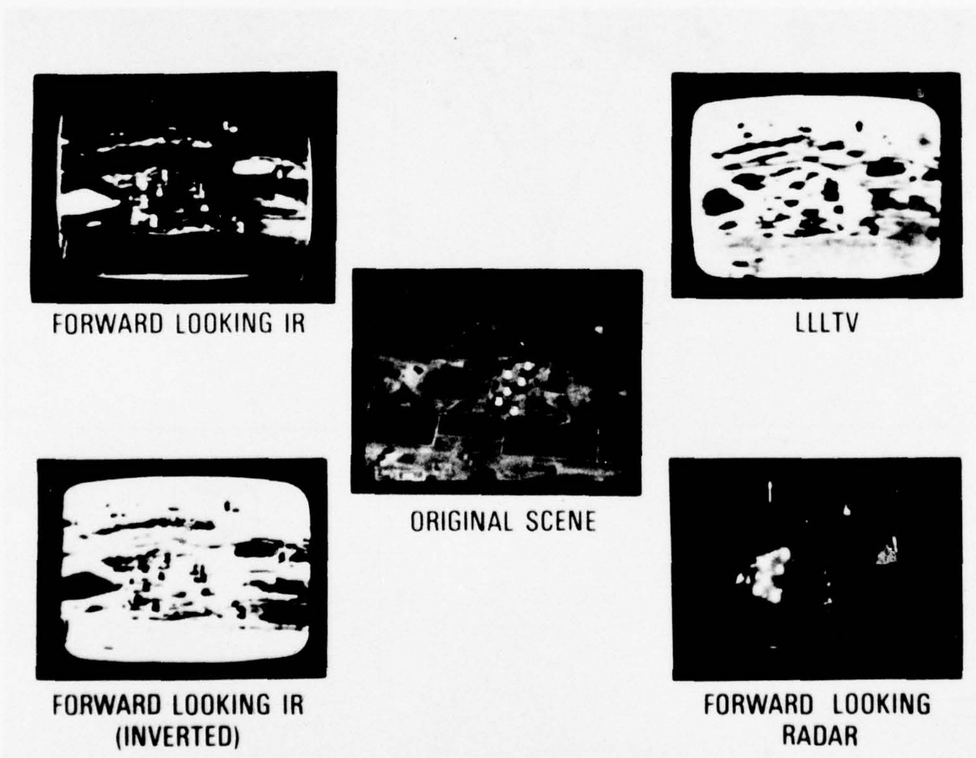

Figure 15. Visual Sensor Simulation

CONCLUSIONS

The Visual Sensor Simulator was developed as a low-cost solution to the problem of simulating airborne visual sensors for pilot-in-the-loop testing. While the present version was found to be highly acceptable for the required purpose, it was recognized that the flexibility of the analog technique would permit the development of additional capability. As is typical of research and development efforts, the available funding was limited. As funds do become available, however, the development of the growth potential that is anticipated in the unit is planned. As was previously noted, the present version does not provide a capability for target identification as the signal processing provides imagery simulation rather than target signature simulation. Further efforts will be made to improve the correlation of the simulated imagery with the return from the real world electro-optical sensor and to evaluate the degree of correlation achieved by the simulation. The addition of radar range rings, controllable target designator cursors and other capabilities can be achieved with additional analog circuits and the use of different cathode-ray tube scan techniques. Some of the proposed additional capabilities are shown in Figure 16. Further development efforts to implement these improvements are anticipated.

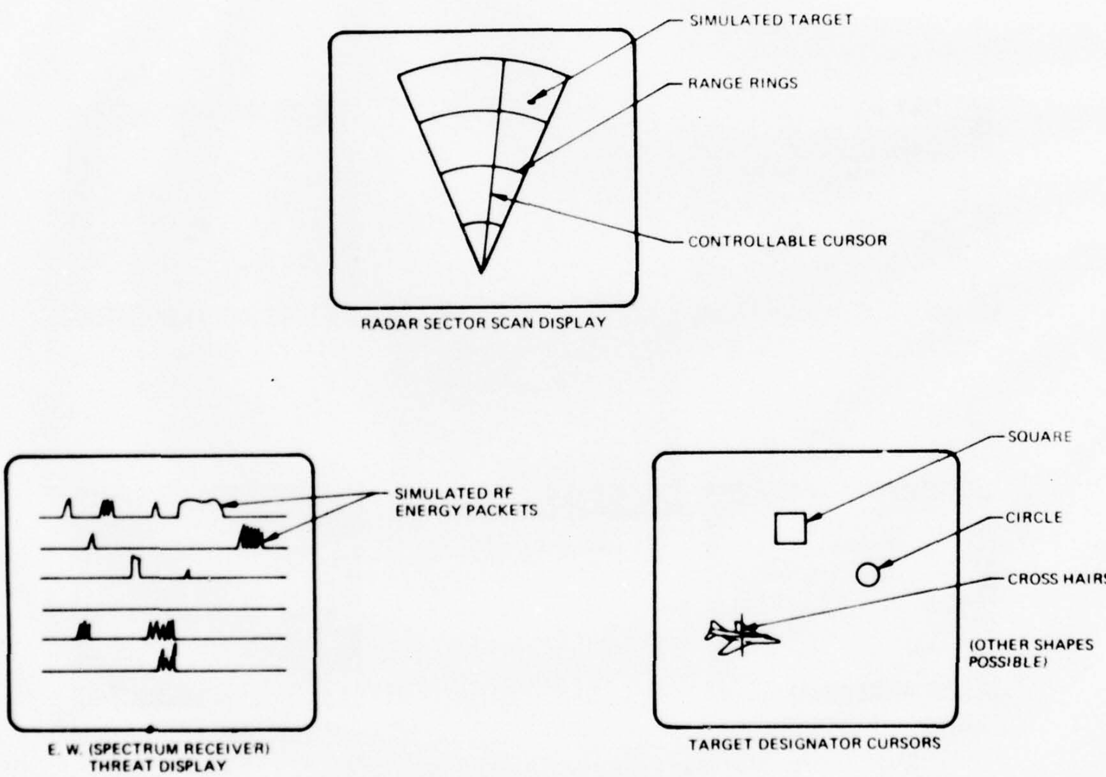

Figure 16. Proposed CRT Display Simulations

ABOUT THE AUTHORS

DR. WILLIAM McCORMICK is a member of the engineering faculty at Wright State University and a consultant for Technology Incorporated. He was primarily responsible for the design of the Visual Sensor Simulator circuitry. His previous experience as a consultant included research investigations in advanced avionics systems for the Air Force Avionics Laboratory. His educational background includes a B.S.E.E. degree from Marquette University, and an M.S. degree and a Ph.D. in engineering from University of Wisconsin.

MR. RICHARD KINNEY is a Senior Electronics Engineer in the Engineering Department of Technology Incorporated. He is responsible for the hardware implementation, detailed circuit design, and system integration of the Visual Sensor Simulator. Mr. Kinney received a B.S. degree in engineering physics from the University of Maine.

MR. WALTER MASON is a Product Line Manager for Technology Incorporated. He is responsible for the management of the Air Force program under which the Visual Sensor Simulator was developed. He is also responsible for a recently awarded Naval Training Equipment Center contract for the development, fabrication, and installation of Submarine Damage Control Trainers. Mr. Mason received a B.S.E.E. degree from University of Vermont, and an M.S.E.E. degree from Kansas State University.

DR. TONY DeTHOMAS is the Deputy Director of the Air Force Flight Dynamics Laboratory Digital Avionics Instrumentation System (DAIS) Program. He was responsible for defining the requirements for a Visual Sensor Simulator as part of the DAIS Control/Display Facility. His previous experience has been in association with the Flight Controls Division of the Flight Dynamics Laboratory. Dr. DeThomas received an M.S. degree and Ph.D. from University of Dayton.

MODELS FOR LIMITING DEBUGGING RESOURCES TO SIMULATION CODING GOALS

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Summary

Models characterizing the step-wise decreasing failure rate associated with the software debugging process are applied to a past computer program development in novel ways. In these applications, the initial number of errors in the program, and the step-size constant, are determined from the error detection rates observed during an initial period of debugging. Formal manipulation of maximum likelihood equations permits estimation of debugging time to achieve a code with specified residual error content. [In any sizeable program it is impossible to remove all errors.]

Introduction and Model Descriptions

Specifying and achieving fixed levels of software reliability is a new concept in industry, even though customers have been suffering from the lack of it for over two decades. In the present paper, probability-based models describing the detection rate of errors in computer software are used to match debugging effort to [simulation] reliability goals, and to predict when a new operational software program will be ready for verification testing. The objective was to develop a prediction technique as an aid to resource conservation.

A variety of theoretical models for determining the number of errors remaining in a computer program, after initial debugging, have appeared in the literature. The main theme of this paper is that, conversely, the debugging resources required to reach a fixed residual error level can be predicted using the same models. The model constants are determined by studying the debug history early in the test and integration phase. Once a data base is established from previous programs, the approach permits estimation of debugging time before any code is written, and allows later updating to improve the accuracy of the prediction when functional testing begins.

Two models were selected for comparison of results:

1) The de-eutrophication process of Jelinski and Moranda [1]

2) Shooman's macroscopic approach [2]

Both are quantitative stochastic models describing the time pattern of occurrence of errors during software development. The models are intended to apply to the situation where the program is sufficiently complete to work for continuous time periods between failures. No attempt is made to take into account the internal structure of a program, due to a scarcity of data in the industry relating individual error types to program structure. Since all software bugs are treated equally, the validity of model output depends on considerable averaging in a large program.

Failure rate at any time is assumed to be proportional to the current error content (number of remaining errors) of the tested program, yielding a step-wise decreasing detection rate, with the times between failures exponentially distributed. This is justified if errors are detected in a random way; caused, for example, by rare combinations of input data and path traversals. The rate initially is proportional to the initial error content, denoted by N. Each time an error is removed, the detection rate is decreased by a constant amount, equal to the step-size Φ. The basic model is shown in Figure 1, where the increasing time between failures is intentionally indicated by spacing.

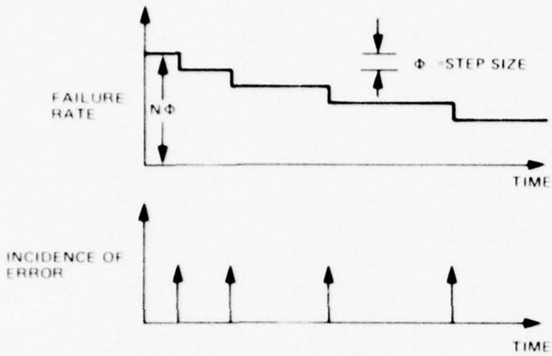

Figure 1. Software Failure

The parameters N and Φ can be estimated from a pair of equations derived by application of the maximum likelihood principle. As shown by the authors, these equations are:

De-Eutrophication Model
(Jelinski-Moranda)

$$\Phi = \frac{n}{NT - \sum_{i=1}^{n} (i-1) X_i}$$

$$\Phi = \frac{1}{T} \sum_{i=1}^{n} \frac{1}{N - (i-1)}$$

X_i = time between the (i-1st) and ith detections

n = number of observations of independent interval lengths X_1, X_2, ----, X_n

T = total debugging time ΣX_i

N = number of errors present at T=0, assumed to be independent of T (i.e., no new errors added during debugging)

Macromodel
(Shooman)

$$\Phi = \frac{n_1 + n_2}{(N-\partial_1)\,T_1 + (N-\partial_2)\,T_2}$$

$$\Phi = \frac{1}{T_1 + T_2} \left[\frac{n_1}{N-\partial_1} + \frac{n_2}{N-\partial_2} \right]$$

n_1 (n_2) = number of observations in functional test interval T_1 (T_2) after debugging time $\tau_1(\tau_2)$

∂_1 (∂_2) = total number of errors found in program by debugging time $\tau_1(\tau_2)$

Although these equations require iterative solution, they normally yield superior results to more explicitly definable moment methods of parameter estimation.

Shooman's equations immediately generalize to n tests, which, if unit-error in size ($n_j = 1$, $T_j = X_j$) brings the model more in line with the approach of Jelinski and Moranda:

$$\Phi = \frac{\sum_{j=1}^{n} n_j}{\sum_{j=1}^{n} \left[N - \partial_j \right] T_j}$$

$$\Phi = \frac{\sum_{j=1}^{n} \frac{n_j}{N-\partial_j}}{\sum_{j=1}^{n} T_j}$$

In fact, comparison of the two models shows them to be identical if ∂_j is equal to (j-1), or equivalently, if $\tau_j = \sum_{i=1}^{j-1} X_i$ for test interval T_j.(*)

(*) In earlier work [3], it was assumed, along with Shooman, that τ_j was defined as $\sum_{i=1}^{j} X_i$

Applications to Space Shuttle

In a software error-prediction study [4] the Jelinski-Moranda model was applied to portions of the Space Shuttle Main Engine Controller computer program to determine residual error content (N-n) of certain modules. The authors of that study noted that a decreasing detection rate was not generally characteristic of the discontinuous verification mode of operation typical with the Shuttle program development. The rate of discovery of errors associated with a phase identified as Integrated System Test Bed (ISTB), did however, show a reduction with time. Since successful prediction required that the software failure-rate fall off in time, effort was concentrated on a part of the ISTB program, designated the Cycling program, which promised adequate data. The time period spanned by testing was roughly from January to September 1975.

The author of this report recognized that, conversely, a purely formal estimate of the expected time to debug a program could be obtained through use of such models.

Referring to Figure 2, the cumulative number of errors detected in the Cycling program is plotted vs. debugging time. Cycling is the name given to the major and minor cycle executive routines plus their first and second level subroutines. It does not include any failure branches. This portion is traversed every 20 milliseconds, the current path taken being determined by input conditions. The program contained 4400 instructions, and a total of 60 software errors were found during the test period from January 31 to June 24. Following submission of the June 24th version of the ISTB program, six additional errors in the Cycling program were identified at the National Space Technology Laboratory (NSTL) prior to August 19th, 1975.

Some care must be taken in applying the models to this data, if erroneous prediction is to be minimized. As to be expected, the beginning data points do not fit the trend of most of the data, due to starting transients in the debugging process. Omitting the first 5 data points, the maximum likelihood equations of Jelinski-Moranda are applied over the 55 points from February 15 to June 20 to estimate N and ϕ (compare the technique in [5], where N is known). The equations then predict a T of 1.3 months from June 24th to remove all but 3 errors from the program, and 5.0 months to achieve a clean code.

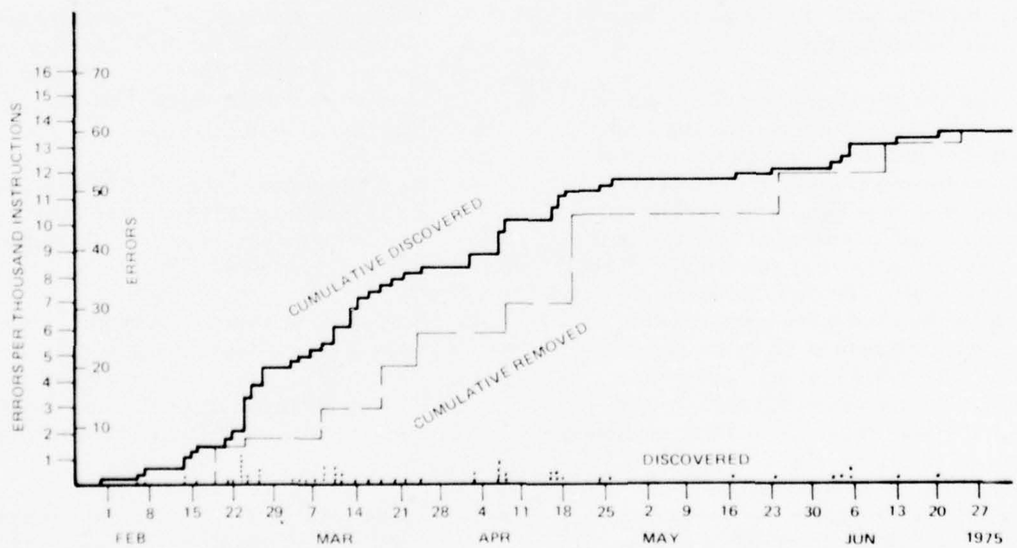

Figure 2. Software Errors in Space Shuttle Main Engine Controller Cycling Program

The first number agrees well with what actually happened (it was estimated from the model that 3 errors remained in the August 19th version). The second number cannot be checked, as follow-up data of that nature from NSTL is not available.

The Shooman equations, using two test intervals, were applied to different parts of the test data, with widely differing results. The first application was over unequal intervals, the 30 days in March, and the 60 days in April and May. This led to an N of 71, and a predicted value T of 40 days vs. an actual 24 days to reach the June 24th level of 60 errors corrected, and 4.8 months vs. 2.7 to attain the August 19th detection status (6 additional errors removed). The second application utilized the first 20 days of March, and the last 20 days of April as the testing period. That predicted an N 0f 67 and a T of 48 days vs. an actual 50 days to reach a point where 7 errors remained in the program, and 118 days vs. 110 actual to remove all but 4 errors.

Comments

In this study a look was taken at models of software reliability growth, specifically with respect to evaluating their use in estimating debugging time. Two models were selected for application that seemed to stochastically describe our conceptual idea of error behavior during development testing.

The numerical results obtained clearly indicate sensitivity to both the testing interval size and the choice of test points. One of the tacit assumptions of these models is that the exposure rate during test (reflecting both manpower and intensity of testing) is the same for time periods of equal length. This is seldom the case in reality, and adjustments have to be made when applying the models. Exposure rate is in some manner embedded in the debug history, and in the application of the model equations, is averaged out in various ways. A normal exposure can be defined in terms of the specific problem at hand, or one may attempt to choose the testing intervals and test points to minimize the effects of variable exposure, as was done in the present case (albeit in hindsight).

In applying the Jelinski-Moranda equations, it was found that the estimates for N were generally a little low, leading to debugging time estimates that were on the low side. This may be due to the model's "folding in," rather than directly subtracting, succeeding data points. If an N of 70 had been estimated at the June 24th point, the estimate T would have been 1.7 months to remove 6 more errors, and 5.8 months to an error-free program.

Application of the Shooman equations to only two test intervals seemed to highlight the variable exposure a program gets during debugging. Extending the method to more tests should minimize these effects, and bring the results closer in agreement with the Jelinski-Moranda predictions.

It is probable that a more precise model of program structure, and the debugging process, will be required to improve predictive results.

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ABOUT THE AUTHOR

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SIGNALING TONE SIMULATION IN AN EMERGING COMMUNICATIONS SYSTEM IMPLICATIONS FOR TRAINING AND UTILIZATION

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SUMMARY

The implications of early simulation of emergent electronics systems are discussed. The effect of simulation on training programs and system usage in the field are illustrated by a recent experiment involving a new military communications system. Potential savings in money and time are identified, as well as increased system effectiveness as a result of early system evaluation. Early simulation is shown to significantly contribute to: (1) more cost effective training; (2) identification of problem areas within the system; (3) a realistic appraisal of system performance; (4) possible improvement of overall system effectiveness; and (5) savings in time throughout the systems life cycle.

The purpose of some aspects of training is, unfortunately, too often seen as a remedial effort to teach someone how to use a piece of equipment or a system which should not have been fielded in the first place (at least in its present form). No matter how cost effective the training process becomes, it cannot produce skilled personnel if the systems they are to work with are too complicated for anybody to ever use them effectively. As General John J. Hennessey said in Signal Magazine (March 77 issue) "Too often we discover that the success of the tactical system is the result of the extraordinary effort of our dedicated men and women overcoming, rather than being aided by, their equipment." It's a case of "if you're not part of the solution, you're part of the problem" and in order to get maximum benefit from the problem of equipment, the ideal situation would be to have a minimum amount of complex things to teach.

However, as we're all aware, it's seldom so.

Tasks in the "Age of Electronics" are becoming more intricate with each new item of equipment, and the total effect of this trend is certainly not likely to make training people in the future any easier. What I would like to demonstrate here is a way in which early simulation of new systems can be used to substantially reduce training problems and increase effectiveness of the user and the system. As an example, I will use a study in which early simulation of the signaling tones to be used in a new tri-service tactical telephone system was examined. Through electronic simulation of the "real-world" way in which this system was to be used, not only was a significantly earlier evaluation of this system possible but also potential training aids, possible problems, and their effects on user performance could be compared.

What emerged from the study were five key issues:

1. Cost effective training begins in early system development - in other words, system development should interact with user training and doctrine requirements to produce a system with the fewest possible training problems.

2. Early simulation can identify potential areas of concern in terms of training and use - the cost of early simulation can be more than recovered in terms of permitting extra lead time for designing training methods and procedures to deal with learning the system, rather than having to "patch up" an inappropriate procedure or training aid.

3. Simulation + User Input = Realistic Appraisal - too often the constraints of the system development process prevent an accurate assessment of the best way to show someone how to use it. Simulating use with actual military personnel allows formation of a more accurate picture of the learning process and can lead to development of a realistic method for teaching military users.

4. HFE + Training = System Effectiveness - if Human Factors Engineering (to provide an easily used system capable of quickly and efficiently performing its function) can be combined with proper training for the user to perform those tasks necessary to operate the system, the result will more than justify the effort involved.

5. Time, the Irreplaceable Resource - The most valuable resource to be saved through early simulation is time. Growth in life cycle costs increases tremendously in the later stages of system development and deployment. A minor correction on an earlier prototype (or, most effectively, on a blueprint) could result in saving truly staggering sums of money as well as considerably

increasing the value of the system to the nation's defense effort. No resource is as critical (or as expensive) as time, and if a simulation device can be used in place of an enormously expensive and sometimes not yet fielded piece of equipment to take an early look at a system, so much the better.

As an example, a new DOD communications system is being produced which uses signaling tones during a telephone call to indicate to the user the status of his call. This system has many of the familiar tones such as dial tone, ringback, and busy signal, and it also has a number of unique tones associated with various calling features such as multiple conferencing, call transfer and nonsecure warning tone. As new features were added to this system, the total number of tones that could be presented to the user during a call reached 16. As an aside, it should be added that this is not a unique example within the field of communications, but rather it is typical of current trends among many electronics manufacturers - reflecting increasing system complexity with increasing interface complexity, a consequence which need not and indeed should not follow.

In order to take an in-depth look at this system, it was necessary to construct a simulation device which could deliver the correct tones during an actual telephone call situation. Due to the astronomical cost of the digital switching system itself, as well as the logistics problems involved in tying up a system which had not yet been completely finished, simulation was an inexpensive means to provide a test vehicle for evaluation. The principal apparatus used in this study is illustrated in Figure 1.

This apparatus was built using common pooled equipment from an electronics shop which services the various directorates of our laboratory. A minimum of new construction was made, in an effort to keep costs of the final system as low as possible.

Since the new digital system will replace an existing analog set-up, it was also necessary to simulate the current analog system in order to obtain some idea of what difficulties would be encountered during the period of transition - i.e., for a considerable time, while the new systems are being fielded, subscribers may have to deal with both sets of signaling tones (analog and digital).

The signaling tones were stored on a Honeywell Model 5600B 14-channel analog data recorder, which was used in the playback mode during testing. Each participant used a TA-341 telephone set to initiate and receive simulated calls. Although the tones were presented to the participants on a self-initiated basis, the actual tones to be presented were controlled by the experimenter through the use of the Tone Controller

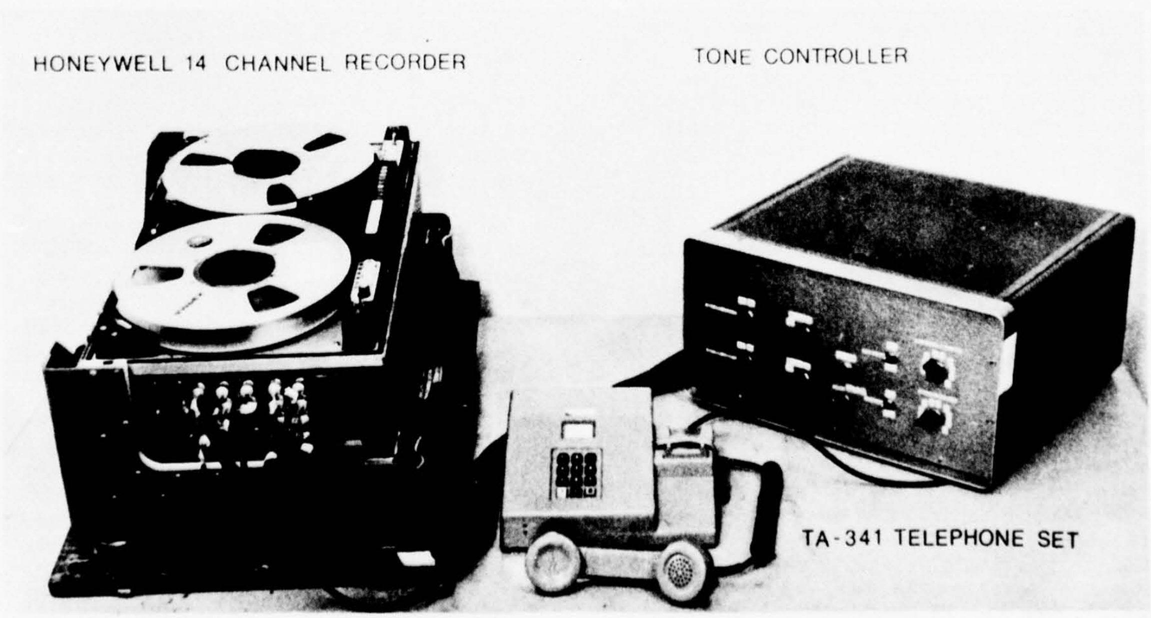

Figure 1. Principal Apparatus

(selector) 1. For example, the participants were told to initiate a call to telephone number 601. The experimenter would set the "hook circuit switch" to Channel No. 1 and the "key circuit switch" to Channel No. 4.

As each participant went off hook, an electronically operated switch in the Tone Selector closed the "hook circuit," which played back a continuous 425-Hz tone (dial tone) into the participants' headset receiver. The participant then keyed in the digits 601. The keying of digit "6" caused the "hook circuit" to open, cancelling the dial tone. Keying the digit "1" closed the "key circuit," which played back 570 Hz, 2 seconds on, 4 seconds off (normal ringback tone). Replacing the receiver on its cradle opened the key channel, cancelling the ringback tone.

The study was divided into two test periods (Phase I and Phase II) separated by a 30-day rest period. The general test procedure is illustrated in Figure 2.

The "basic" conditions were those which the user would encounter during a normal call. As indicated in Figures 3 and 4, these include such things as dial tone, ringback and busy signals. The "full service" conditions utilized the full capabilities of the system and included tones for such features as call transfer dial tone (situation number 18), broadcast conference notification tone (15) and others as noted.

The Phase I test period was concerned with acquisition of initial proficiency, and identification of the signaling system's problem areas. The Phase II test period was purposely scheduled after a long period where the participants received no practice and/or training related to the study. This was in order to address the question of how long the participants would retain their proficiency.

The two test periods were structured similarly; first testing on the two basic conditions, then on the two full-service conditions. One of the two participant groups was assigned to analog test conditions only, the other to digital test conditions only. The resulting arrangement simulated subscribers first being subjected to the basic tone situations and later, after having gained experience with the system, moving on to use the full services on the same telephone instrument (analog or digital). This test design was considered realistic for the full-service subscriber who would first familiarize himself with the basic services before attempting to use any of the more sophisticated features. The test design also allowed for isolating and evaluating how well subscribers would use the basic services.

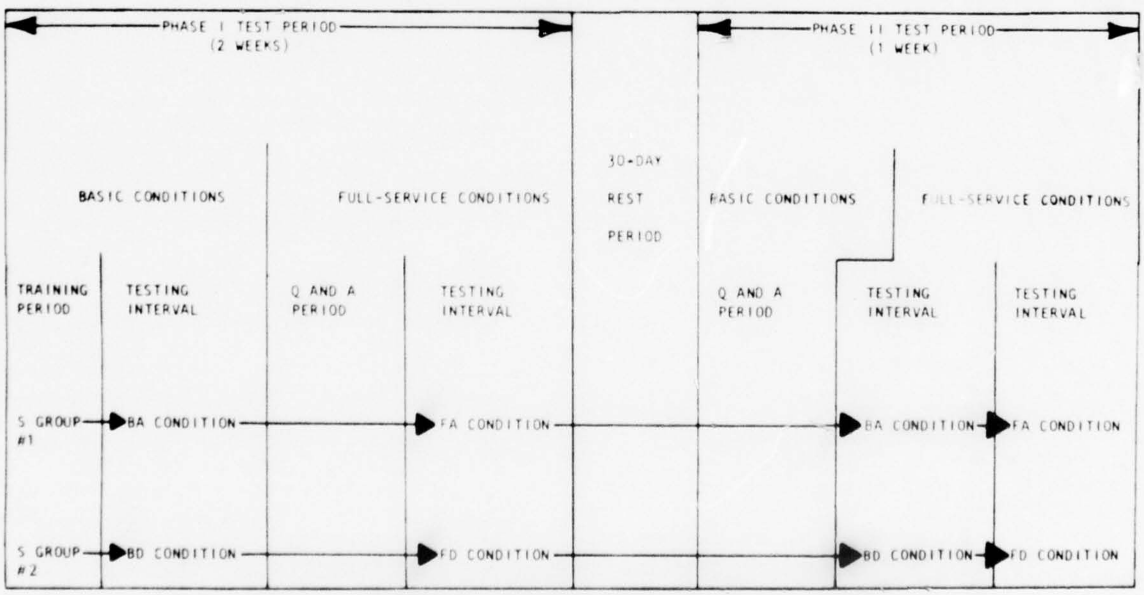

Figure 2. General test procedure

[1]For complete details on this apparatus, see: Wolfe, O. C. Apparatus for telephone tone study, HEL Technical Note 5-76, September 1976.

Twelve military personnel (five officers, seven enlisted) from the 42d Transportation Bn, Ft. Meade, MD, participated in this study. Due to the nature of the study, it was necessary that the participants have normal hearing and tone acuity. Since intelligence scores were needed for purposes of possible correlation with speed and ease of learning, each participant was given the Otis Quick-Scoring Mental Ability Test (high school, Form A). The range of IQ scores was 82 through 124 (mean IQ was 107). The participants were matched by tested IQ level and randomly assigned to either analog or digital conditions.

The procedure followed for each simulated call in the test runs was basically the same. The participants were directed to place or respond to some specific simulated call. They were given the opportunity to review the abbreviated and/or detailed written instructions on the call-processing features. During the call process, the participants would receive a signaling tone. At this point, they would choose an answer from their list of possible answers and mark it on their answer sheets. After all participants had put down their answers, the experimenter told them the best answer. This form of reinforcement was considered analogous to the "experienced-user advice" usually available to the novice subscriber. After all discussion on the "best answer" was completed, the participants would wait for further instructions from the experimenter.

Three levels of response quality were used to allow the participants to express incremental advances in learning. The three levels were defined as follows:

Level One: acceptable but less-than-satisfactory responses. At this level a correct response demonstrated that the participant knew the correct basic reaction to a tone, but had no real understanding of its meaning (e.g., hang up, but you're not sure why).

Level Two: satisfactory responses. At this level, a correct response demonstrated that the participant knew the correct tone reaction and its general meaning (hang up ... something is busy -- either the line, the trunks or the special service requested - you don't know which).

Level Three: more-than-satisfactory responses. A correct response at this level showed that the participant also understood some of the signaling-system nuances that were not crucial to subscriber effectiveness, but which were beneficial. (Hang up ... the number called (line) is busy.)

For both analog and digital conditions, participants showed a significant degradation in performance when transitioning from basic to full-service levels. IQ was highly correlated with the number of trials to reach criterion at each level; a higher score on the general intelligence test indicated that fewer trials would be needed to reach criterion. Certain tone conditions demonstrated noticeable deviation from the mean (>1) and were tentatively identified as presenting obstacles to complete mastery of the system.

As can be seen in Figures 3 and 4, the participants had difficulty with certain of the tone situations involved in each of the conditions.

As the number of tones and tone situations increased from basic to full-service, participants experienced difficulty not only in learning new tones, but also in retaining previously learned material. This inhibition to learning was greater for certain tones and tone combinations.

In Figure 4, for example, the preempt tone in the basic digital (BD) condition required 11 trials before the participants reached criterion. In the full-service digital (FD) condition, the normal time to reach a level-two response criterion for the same tone was only two trials; however, during a conference call (situation 22) it required 11 trials before the participants learned to differentiate between the preempt tone and an alternative possibility (situation 20, conferee disconnect). The preempt tone is a $1\frac{1}{4}$-second burst of 440/620 Hz dual tone, while conferee disconnect consists of a 1-second burst of dual 480/620 Hz tone, only a 40 Hz difference. Conferee disconnect tone was rated as one of the three most difficult tones by 10 out of the 11 participants who completed the questionnaires at the end of Phase II testing.

Another situation of concern to the participants was the 1-second duration of the conference-notification tones. Because the tones are presented immediately as the receiver is lifted off-hook, the participants frequently noted that, unless they put the receivers to their ears while still holding down the interlock device on top of the phone and then lifted their fingers from the phone, it was very difficult to hear a sufficient amount of the tone to discern whether it was a preprogrammed--conference or broadcast-conference notification tone. Since it is unlikely that this will become standard operational procedure for answering the telephone, it is apparent that some modifications was called for in the area.

Written instructions were presented in two forms, a one-page set of brief instructions which gave only a minimal description of call processing information, and a detailed set which gave elaborated instructions combined with a narrative description of the frequency and cycling rate of the tones involved.

Of the 11 participants who completed the questionnaire, five preferred the abbreviated instructions, and six preferred the detailed instructions. The lack of clear preference, combined with the length of time required to master the full-service conditions, tends to suggest that neither version is particularly effective in transmitting the needed information. It can be anticipated that the more traditional type of written instruction, such as was used in this study, will probably be at least somewhat inadequate to the task of teaching the new subscriber how to use the system.

In general, the study served to illustrate the importance of early simulation of complex systems as a method for realistic evaluation and remediation. In terms of the key issues raised earlier:

(1) Cost effective training - early simulation of this system permitted the

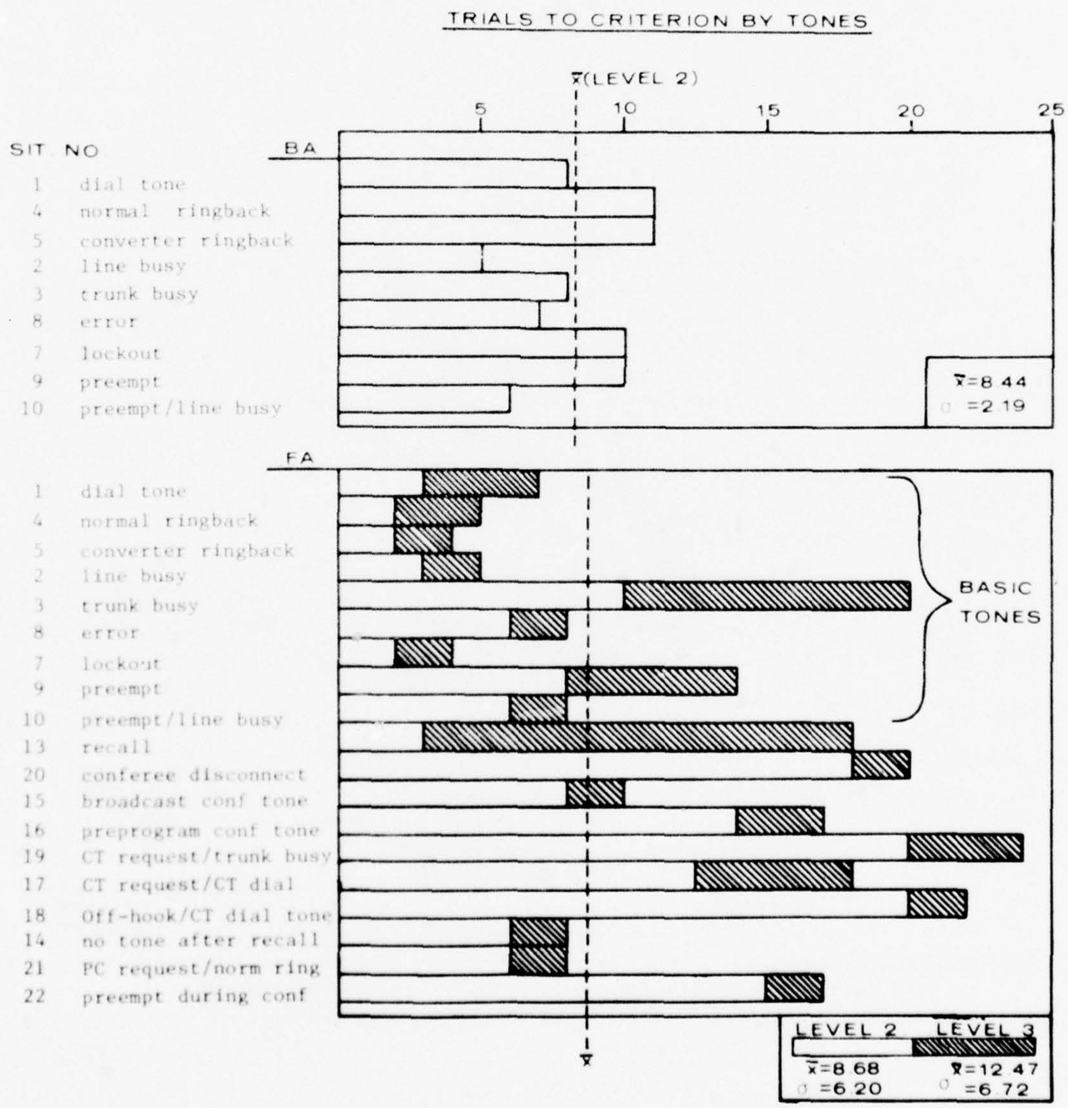

Figure 3. Trials to criterion by tones--analog conditions

development of a relatively inexpensive training device which can be modified and improved for use with this and other systems. Requests have already come in from Army training facilities for information about this device. By extending the lead-time for producing a training aid, significant increases in quality and effectiveness can be gained.

(2) Identifying potential areas of concern - problems of complexity and training methodology emerged much earlier than they would have without simulation. This will permit the expenditure of extra remediational efforts in those areas where they will do the most good. Hopefully, a combination of system "fixes," combined with development of more effective aids to learning the system (e.g., perhaps flow-charting the instructions), will result in the fielding of a system which is "part of the solution" to reducing the complexity of the military electronics environment.

(3) Realistic appraisal - use of military participants in a simulated operational exercise was essential. Too often, systems are evaluated by the engineers who built them and the government representatives who helped monitor the design and fabrication process. It's like trying to proofread a term paper

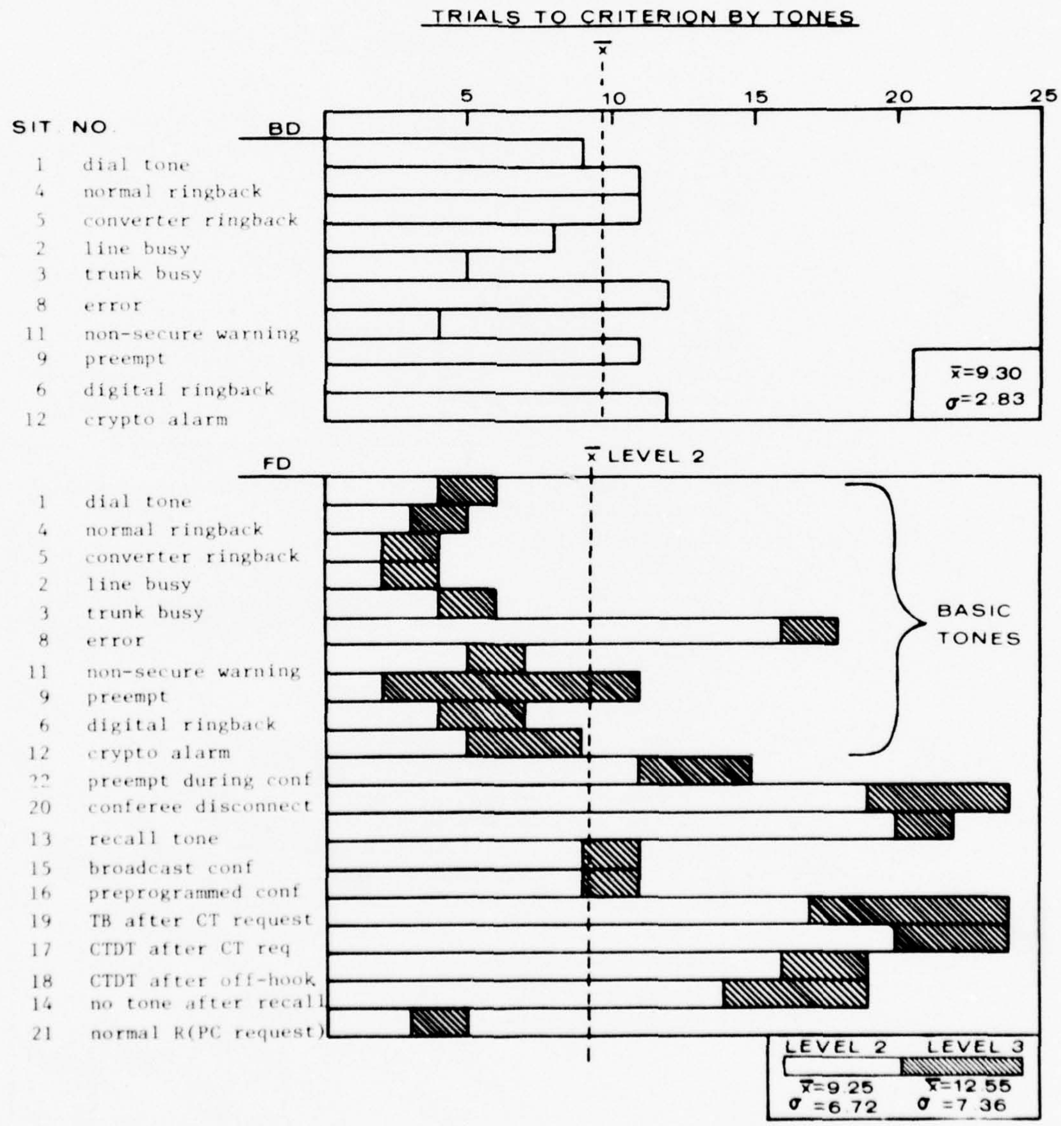

Figure 4. Trials to criterion by tones--digital conditions

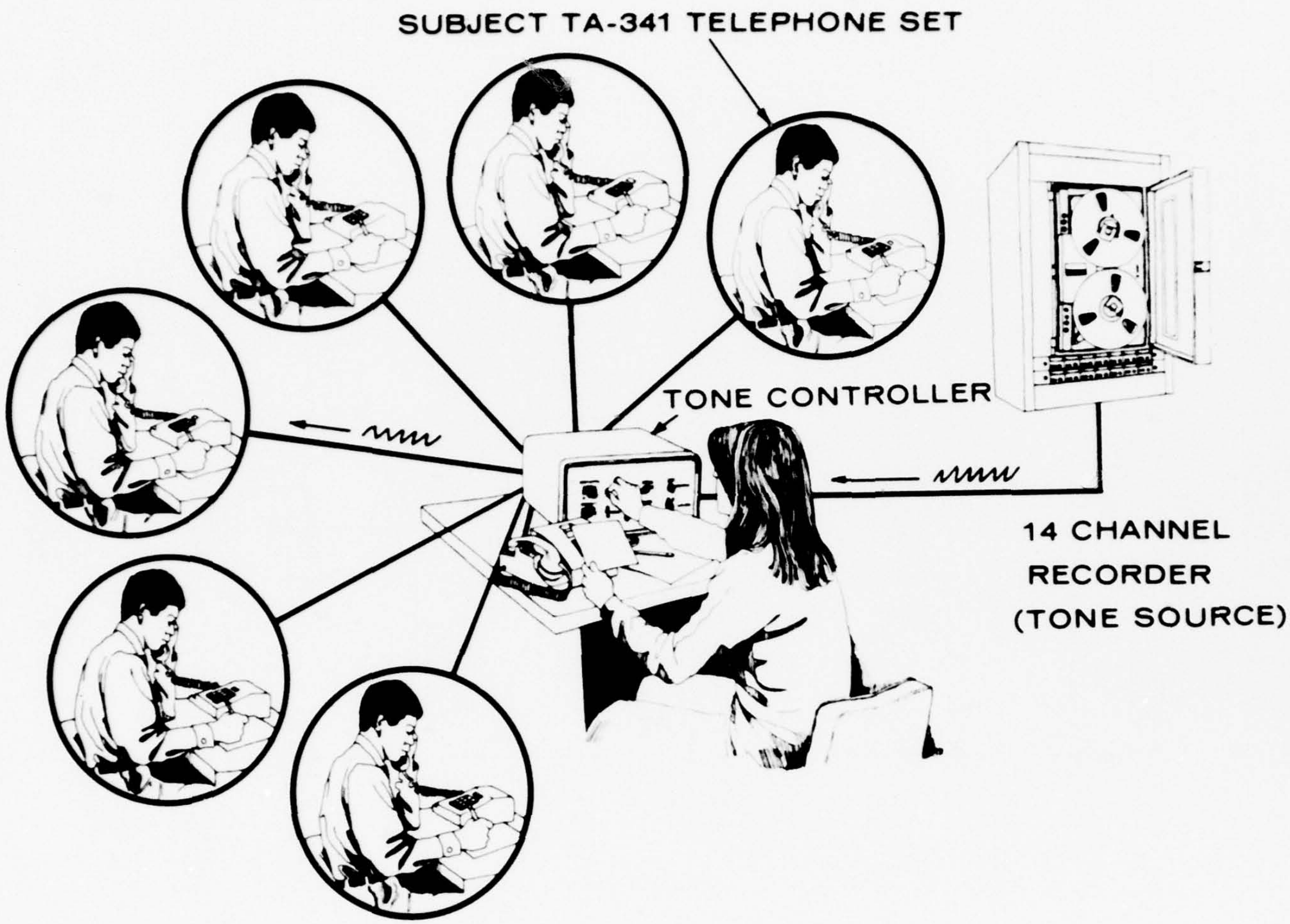

Figure 5. General apparatus arrangement

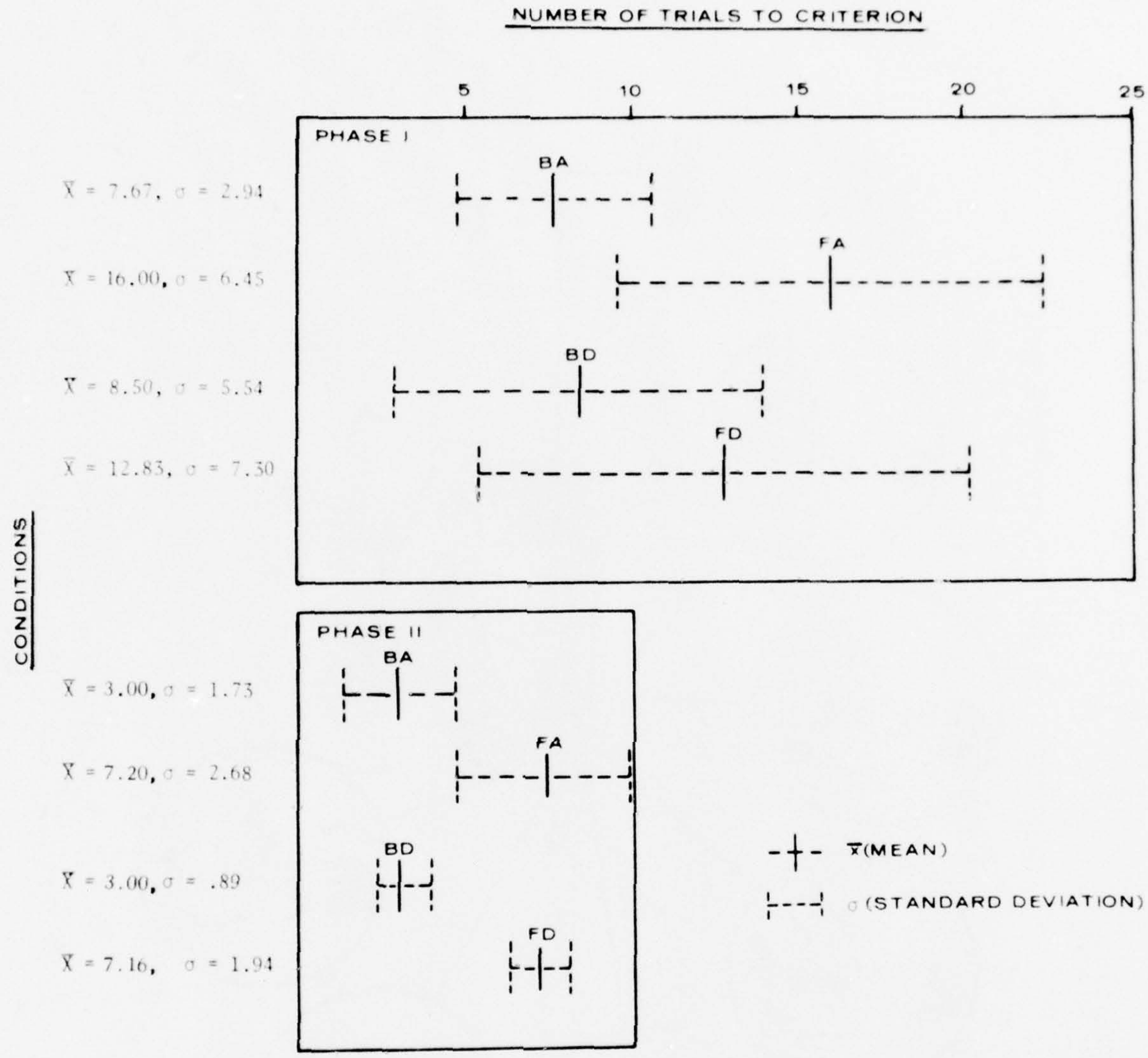

Figure 6. Trials to criterion as a function of condition and level of treatment--Phase I and II

that took months to research and write - you tend to fail to perceive what will go through the mind of the naive reader, and you frequently omit information which is well-known to you but unknown to the reader. Similarly, engineers and scientists quite often forget that the majority of eventual users of their products are interested in the device as a means to accomplish a mission, rather than an end product in itself. If you need a jeep to get through the mud, a Rolls-Royce will be of little value even if it is a much more mechanically sophisticated example of the genre.

(4) System effectiveness - early simulation of emergent systems can result in a more effective program of training and utilization. Good human factors input and development of appropriate training aids can combine to make the man-machine interface with a new system a pleasure instead of a chore. And a system that's easy to understand and use in peacetime conditions will be an absolute asset in times of conflict.

(5) Time - to be used effectively, the resource of time requires that a system and its interaction in a realistic environment with the user be examined as early as possible.

In summary, time can neither be created nor destroyed, it can only be spent productively. It is my intent in having presented this analysis to illustrate a use of simulation devices which permits the most effective "spending" of this most valuable resource. Through a combination of good human factors input during development, early simulation, and effective training procedures, maximum value will be obtained in terms of the resources expended.

Simulation can be more than a training methodology - it can be an invaluable resource in itself.

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CONSERVING RESOURCES THROUGH TIME-DOMAIN
SONAR SIGNAL SYNTHESIS

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INTRODUCTION

Energy, time, fuel, manpower, and the price of maintaining equipment are all resources exhibiting rising cost curves, and in some cases, also shrinking reserves. To use these resources indiscriminently to train new recruits and upgrade experienced operators is a luxury that all nations can no longer afford. Fortunately, for some applications, cost effect alternatives that conserve our valuable resources are now available. Training sonar operators on real-time simulation equipment in a ground-based school is one such application. Recent advances in computational and storage hardware have made it possible to produce complex signals in real-time to simulate the diverse sounds that are picked up by hydrophones in sonar systems. Early sonar simulation systems had to produce audio sounds that imitate those heard through the sonar headphones as received from the real world environment. Through advancements in sonar and signal processing technology, the Fourier spectrum of received acoustic signals are also displayed. A viable simulation trainer must, therefore, follow suit and produce stimuli to the student that must not only "sound" right, but also have the same salient spectral features as the acoustic signals received by sonar hydrophone arrays in the real world.

Modern sonar simulation trainer systems have been bounded by two philosophies of design commonly referred to as "simulation" and "stimulation." "Simulation" systems model everything in the real world to produce signals to drive meters, cathode-ray tubes (CRT) and earphones that would imitate everything that a sonarman would expect to see and hear in an actual operational sonar suite. No actual operational sonar equipment is used. A "stimulator" on the other hand uses operational sonar equipment and real-time modeling techniques to generate signals that would simulate signals normally received by such equipment. The principal difference between the two extremes lies in whether or not the operational equipment effects are modeled. For any given system, the approach chosen can strongly impact the cost of the system and the ultimate realism of the simulation. It is not always a clear-cut decision at the outset as to whether one or the other approach is more economical, or even possible. Often a mixture produces the best solution. However, the methods finally used are often dictated by constraints placed on the designers by the customer.

For those whose interest in sonar simulation is recent, this paper can be read as a sequel to an earlier paper by Wang [1] where a synopsis of the necessary sonar and trainer background information is presented. Only some facets of this background information is presented in this paper for completeness.

This paper discusses some real-time sonar signal generation methods and shows how some of these signals can be analyzed to determine their spectrum. The need to analyze the spectral nature of these signals lies in the fact that for the sake of stability, repeatability, reliability and economy, digital methods are used to synthesize the signals. However, to reproduce the signals that drive the actual displays, these signals must eventually be converted to an analog form. Again, for the above mentioned advantages of digital signalling, the process of merging these signals are often held off to the last, most reasonable, part of the processing pipeline. This would sometimes require successive sampling of interpolated signals which then destroys the constraints of Nyquist's sampling theorem. But since the spectrum of the composite signals are eventually analyzed and electronically displayed for source signature identification, the effects of the various intermediate processing steps on the spectrum of the ultimate signal becomes very important.

It is obvious that synthesizing sonar signals in the spectral domain is possible and even desirable in some instances. However, the pros and cons of time-domain versus spectral-domain synthesis techniques will not be addressed in this paper. Instead, discussions will only concentrate on the former means of acoustic signal synthesis.

DIVERSITY OF SOUNDS

Sounds that contribute to the composite signal picked up by a hydrophone array can be broadly classified into three groups as noises caused by water movement, by marine life, and by man-made sources. To provide an appreciation for the diversity encountered,

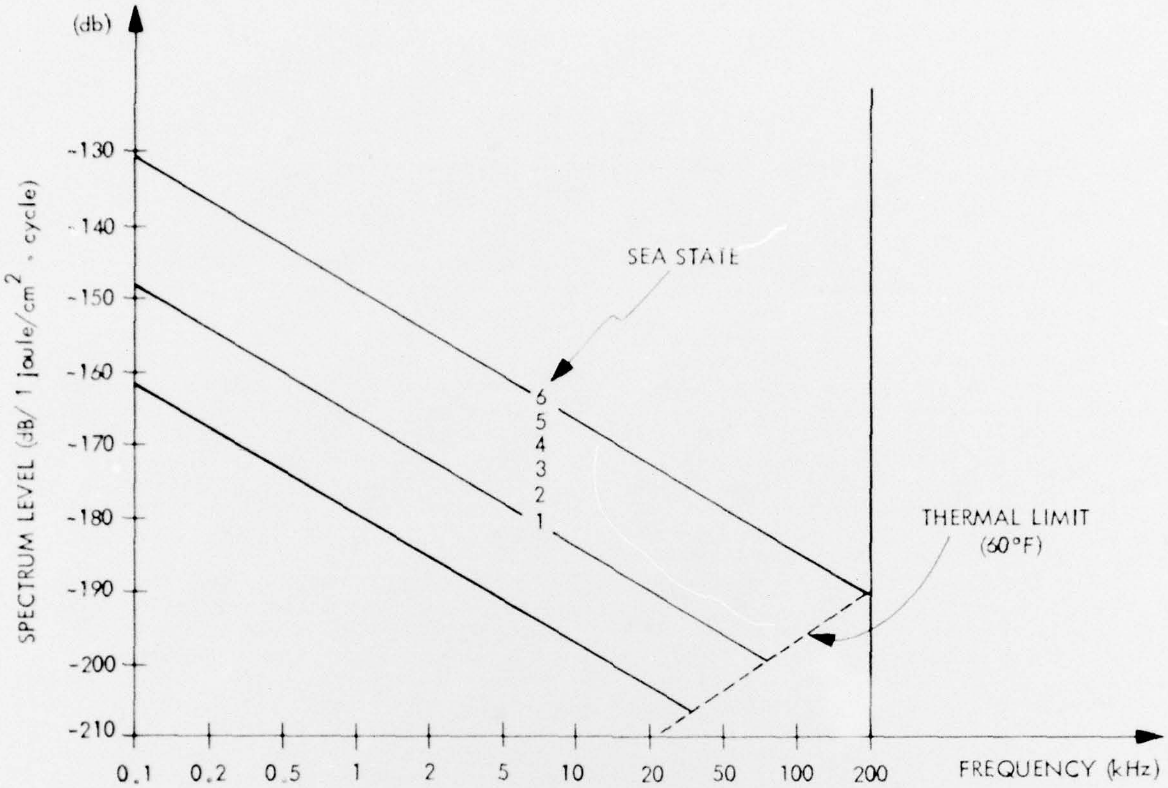


Figure 1. Amplitude Spectrum of Water Noise

each class of noisemaker will be discussed briefly.

Noise generated by water movement has been measured by many research teams under a variety of conditions at numerous locations. Figure 1 shows an average spectra of water-movement-related underwater sound, as a function of sea state, which is commonly measured in terms of wave height. It is interesting to note that the spectrum is not flat, but falls with rising frequency. The minimum water noise can be attributed to inherent thermal noise in the water and to the motion of general marine life present in the environment. This minimum is rarely exceeded in actual measurements. The origin of noise due to water movement ranges from water splashing on foreign objects, such as a shoreline and the hull of a ship, to the impact of water on water as in breaking of wave crests. Other examples of noise due to water movement can be found in the literature on sonars [2].

Marine life of all types also contributes to the general noises found in the ocean. Many marine creatures emit sounds that have characteristic signatures. The toad fish is one which emits a loud sound, much like a violin string stroked by a bow. Others, like the porpoise, produce such a variety of sounds that it is useless to try to identify them. For instance, the porpoise is known to bark like a dog, gobble like a turkey and sometimes emit a distinctive bubbling whistle. There are other marine inhabitants that produce practically imperceptible sounds that become annoyingly audible only when huge numbers of them are active at the same time. Two such creatures are the snapping shrimp and a small fish called the croaker. Noise generated by this last group of noisemakers is both seasonal and locality-bound.

The principal source of man-made noise in the open seas is shipping. Sounds from a given ship depend on its type, size, design, and mode of operation. The sound actually received by a hydrophone depends on the depth and temperature profile of the ocean, as well as the relative location of the ship emitting the sounds to the hydrophones picking them up. However, the sounds emitted by ships are very distinctive, and are effectively used to identify the source. A trainer, therefore, must duplicate shipping sounds to such a degree of exactness that a student will be able to transfer the knowledge he gains from the trainer to the operational world. This usually means a reasonably faithful

reproduction of both the sound waveform and its spectra.

The spectral level of shipping noise does not differ much from general water noise, except for a steeper negative slope and the manifestation of distinct peaks. Engine and propeller noises produce characteristic frequencies, with the latter being complicated by such factors as cavitation [3], mechanical vibration and singing [2], all resulting in a complex modulation of the basic noise.

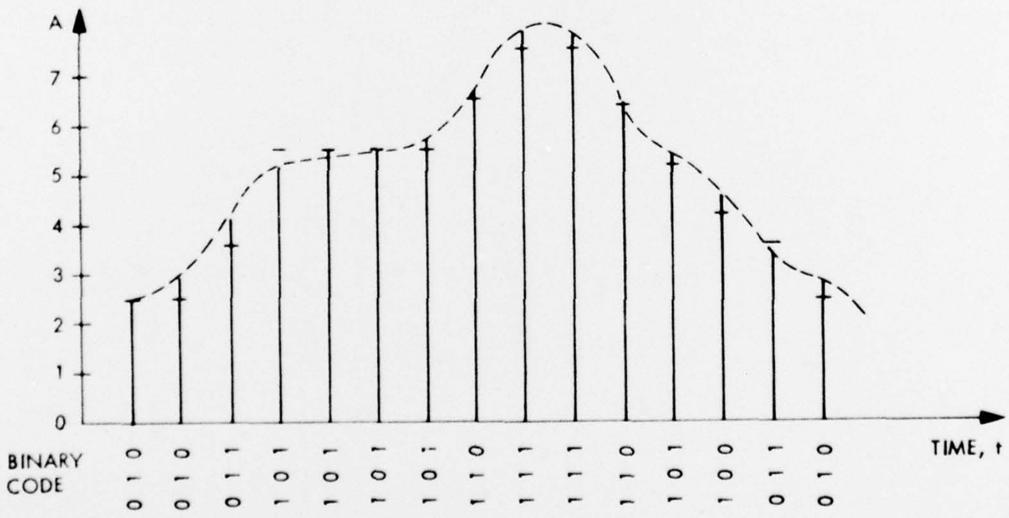
The purpose of this discussion is to point out the wide range of noise sources, and types and effects that a trainer must produce to provide necessary training cues and a "realistic" effect. The very breadth of characteristics that need to be modeled require a parametric sound source that will produce a proper composite signal. Methods to synthesize and analyze such signals will be the topic for the rest of this paper.

DIGITAL SOUND GENERATION IN THE TIME-DOMAIN

In the frequency domain, the acoustic input to the hydrophones is seen to consist of pink* noise, with random line frequencies occurring either singly or in families. These signals are reflected in the time-domain as a complex composite of noise, single frequency signals and multiple frequency signals. As found under normal operating conditions, the signal characteristics are also time variable, or statistically nonstationary.

The composite sound generator in a sonar stimulator is typically a self-sustaining parametric system that changes sound characteristics only in response to environmental changes. A given set of characteristics is usually determined through software models calculated by a general-purpose computer. The resulting parameters are then input to the sonar sound generator at prescribed intervals to produce an essentially time-varying scenario.

Since the sound generator is self-sustaining between updates, much of the data needed to produce the proper sound signals must be stored. To conserve hardware, the data is stored in as coarse a resolution as the simulation will allow without compromising the nature of the signal used to stimulate the sonar system. This discussion will assume the synthetic sonar sound signal to be digitally generated. A digitally generated sound signal is represented by a series of binary numbers generated in the following fashion: A continuous wave is periodically sampled, and the resulting discrete amplitudes are then quantized and represented by a binary number. This is illustrated in Figure 2.



o DOTTED CURVE DENOTES ORIGINAL ANALOG SIGNAL WAVEFORM

o VERTICAL BARS DENOTE SAMPLED SIGNAL

o HORIZONTAL BARS DENOTE QUANTIZED REPRESENTATION

Figure 2. Digitized Signal and Corresponding Binary Code

*Pink or colored noise is used to describe noise with a nonuniform spectrum in contrast to white noise which is used to imply a uniform spectrum.

From sampling theory it is known that if the original waveform contains no signals having frequencies greater than ω_c, then by sampling the analog signal at a frequency ω_s which is greater than $2\omega_c$, the original signal can be recovered completely when low-passed by an ideal filter with an upper cut-off frequency of ω_c. In practical systems, the ideal conditions of sampling theory are not achievable*, therefore, higher sampling rates and different interpolation schemes must be used. The interpolation process is typically performed by a digital-to-analog (D/A) converter. The output is then filtered by a realizable low-pass filter to discriminate against frequency components introduced by digitizing, quantizing, and interpolating.

When digital data representing various waveforms sampled at different rates are combined without first interpolating within the intrasample space to form a composite waveform, incorrect values will result everywhere except where the samples of all component waveforms coincide. One solution to this problem is to convert each signal to its analog equivalent and perform all the combining processes either directly in the analog domain, or in the digital domain after synchronizing the data through a common redigitization. An alternate method is to estimate the values of all the waveforms at the desired sampling time by interpolating between the bracketing samples and using the estimated values in the processing. The latter method has the advantage of keeping all the processing in the asynchronous digital domain without the undesirable steps of converting and reconverting between the digital and the analog domains. The net effect of estimating the values of a given waveform between known samples is a multiple sampling of the original analog signal. The "sampling" in the digital domain may be at a higher or lower rate than the original sample, and may even be a mere constant delay at the sampled function. Whatever the condition, the method used to interpolate and resample will affect both the amplitude and phase spectra of the original signal. Since amplitude and phase errors in the spectral domain affect the ultimate signal displayed by the sonar equipment, their effects must be carefully studied. Before expounding on the spectra of signals generated by time-domain processing of digitized signals to simulate acoustic sounds, we need to digress to a discussion on the source of these digitized signals.

SIMULATING SOUND SOURCES

Sound sources other than biologics are produced as (a) broadband (pink) noise, (b) narrowband noise, and (c) single or families of distinct tones. Many methods are available for simulating the noise sources in real-time. One method, as depicted in Figure 3, uses a uniform spectrum pseudorandom number generator that has a long repetition cycle to drive a parametrically controlled bank of one third octave bandpass digital filters to produce either a broad or narrow-band digital noise source that has the desired spectral characteristics. An

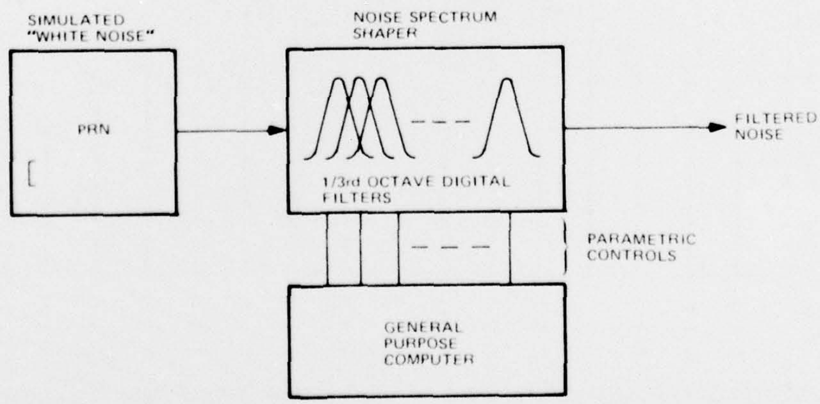


Figure 3. A Broad or Narrow Band Noise Simulator

*The ideal low-pass filter with a sharp cut-off at ω_c between the passband and stopband produces a (sinx/x) interpolation function which is noncausal, and hence, not practically realizable.

alternative noise generating technique is to synthesize a parametric signal source that has the desired spectral envelope which can then be customized by adjusting the parameters to produce other envelopes that fit the environment being simulated.

Single tones and families of distinct frequency signals are simulated by sampled audio signal sources, exemplified by sawtooth and squarewave generators, that are known to have the desired family relationships. This signal is then passed through a digital filter to produce the final signal that has the desired spectral and audio qualities. Figure 4 shows the block diagram of an example of how much a system would be implemented.

Prior to feeding the various digital signals to circuitry that drive the simulator or stimulator, the signals must first be properly mixed. In the case of stimulators, only proper delay and attenuations need be introduced at this point to simulate physical displacements between hydrophones in an array. By doing so a proper sense of relative direction and distance of a signal source would be introduced to the simulation. When time-domain processing is used, and the effects of a beamformer [1] are to be simulated, the time (or phase) delayed signals must also be recombined in the digital domain to form a composite signal with which to drive the CRT. In such a situation, a resampling of the signal will be necessary. When this resampling occurs at locations other than where the primary signal is sampled, the process must operate on an interpolated version of the input digital signal. Such resampling often introduces errors in the spectra of the signal that results. Therefore, it behooves us to understand the effects introduced by this process.

SPECTRUM OF DIGITAL SOUND

Suppose a spectrally shaped digital noise source is to be combined with other digital signal sources to produce the waveform shown in Figure 5a. Mathematically, the waveform in Figure 5a is an amplitude-modulated version of the pulse train in Figure 5b, where the modulating signal is shown in Figure 5c. If the analog signal in Figure 5c is a true sonar signal, with the spectrum shown in Figure 5c', then the spectrum of the digitally generated sound is calculated by computing the convolution of the Fourier transform of Figure 5c' with the Fourier transform of Figure 5b', to give Figure 5a'. The derivation of these results are well known and can be found in any book on sampling theory [3]. The effects of sampling can be removed by filtering the waveform of Figure 5a with a low-pass filter that has a cutoff frequency of ω_c. Note, however, if $\omega_c < 2\omega_s$, signal components from higher frequency bands will fold into those in lower frequency bands to produce a distortion of the resulting time domain signal that cannot be removed by filtering. This effect is known as "aliasing," and is one to be avoided.

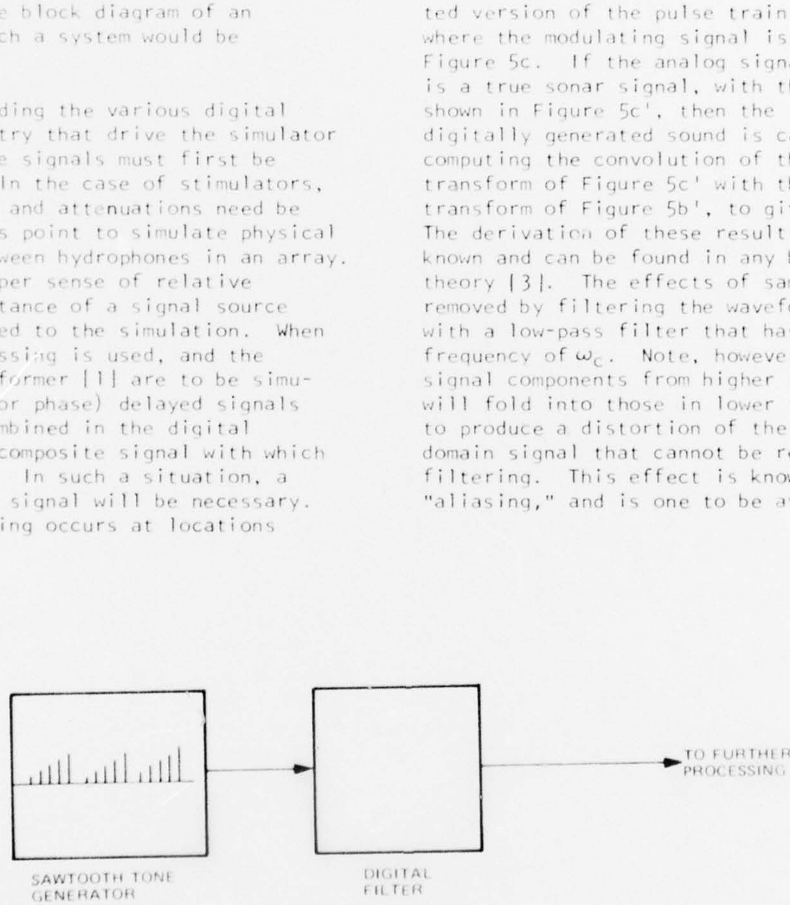


Figure 4. A Line Family Generator

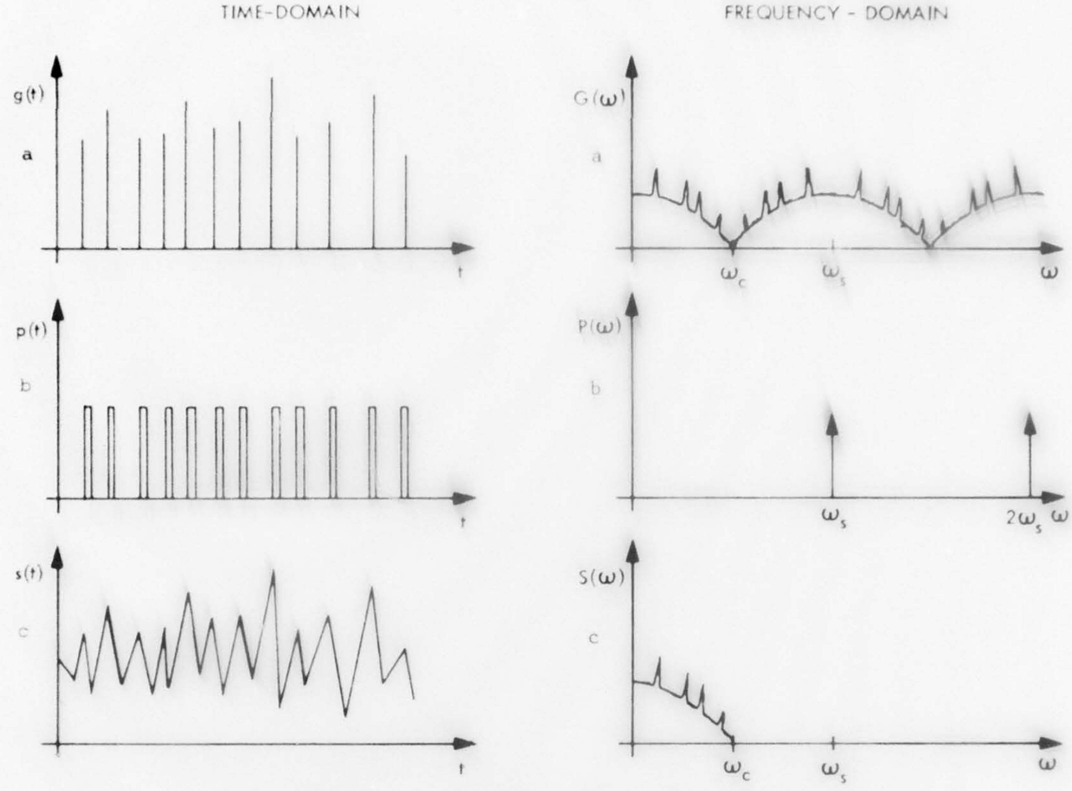


Figure 5. Spectrum of Sampled Sonar Sound

With this introduction to the spectral effects of sampling, we can proceed to the business of examining how interpolation and resampling affects the spectrum of the signals that are produced.

SPECTRUM OF INTERPOLATED SOUND

Starting with a sampled signal, it is possible to fill in the intrasample region by some interpolating function. Two commonly used polynomial interpolators are the zero-order interpolator (sample-and-hold as in Figure 6a) and the first-order interpolator (linear interpolator as in Figure 6b).

The zero-order interpolator consists of a circuit that will hold an impulse input at an amplitude equal to the "amplitude" of the impulse from the time it occurs, until some time $t = T$ later, at which time another impulse occurs. The interval T is usually the period of the sampling function $p(t)$. Stated formally, the input of one impulse with "amplitude" A occurring at $t = 0$ is

$$e_{in}(t) \triangleq A\delta(t) \qquad (1)$$

The output response to $e_{in}(t)$ is then

$$e_o(t) = A\left[u_{-1}(t) - u_{-1}(t-T)\right] \qquad (2)$$

where $u_{-1}(x)$ is defined to be a unit step occurring at $x = 0$. The impulse response of a zero-order hold circuit is thus the difference between two unit steps shifted by T in time. Taking the Laplace transform of $e_o(t)$ gives the transfer function of the zero-order hold circuit to be

$$G_h(s) = \frac{1}{s} - \frac{e^{-sT}}{s} = \frac{1-e^{-sT}}{s} \qquad (3)$$

By substituting $j\omega$ for s and $\cos\omega T - j\sin\omega T$ for e^{-sT} we get the amplitude and phase spectrum to be

$$G_h(\omega) = T\left|\frac{\sin\omega T/2}{\omega T/2}\right| \cdot \underline{\Big/ -90^\circ + \tan^{-1}\frac{\sin\omega T}{1-\cos\omega T}} \qquad (4)$$

The time-domain response of a sample and hold circuit to an impulse input function and the amplitude and phase spectrum of the zero order interpolation circuit are given in Figure 7.

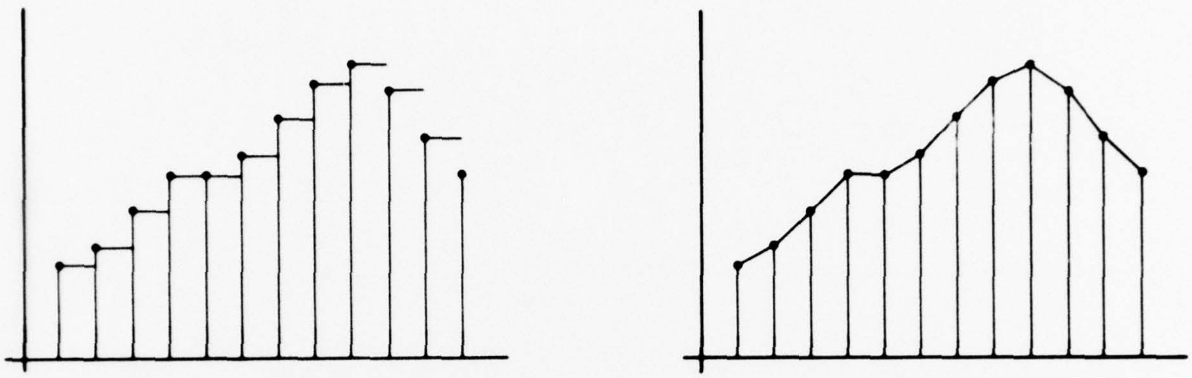


Figure 6. Zeroth- and First-Order Interpolation

Suppose $f(t)$ is a bandlimited function that is sampled by a periodic train of impulse functions $p(t)$ to form $f^*(t)$. If the Fourier transform of $f(t)$ is $F(\omega)$ and the period of $p(t)$ is T, then the Fourier transform of the sampled wave $f^*(t)$ is given by

$$F^*(\omega) = \sum_{k=-\infty}^{\infty} F(\omega - 2\pi k/T) \qquad (5)$$

If $f^*(t)$ is passed through the zero-order hold circuit, the resulting signal is given by the convolution of $f^*(t)$ with the impulse response of the zero-order hold circuit. That is,

$$\hat{f}(t) = f^*(t) \circledast g_h(t) \qquad (6)$$

where $\circledast$ denotes the convolution operator. With $G_h(\omega)$ the Fourier transform of $g_h(t)$, the Fourier transform of $f(t)$ is given by the product

$$F(\omega) = F^*(\omega) \cdot G_h(\omega) \qquad (7)$$

The zero-order hold function, therefore, acts as a low-pass filter with a phase lag.

To understand the impact of time-domain processes on simulating sonar and, in particular, beamforming in a hydrophone array, it is necessary to analyze such a system†. By way of illustrating the effects and the need for such analysis, an example is presented.

THE SPECTRA OF A SIMULATED CIRCULAR HYDROPHONE ARRAY BEAMFORMER

Let the hydrophones forming an array lie in a circle and an acoustic wavefront ripple through this sensor array as shown in Figure 8. At any instant in time, the source signal sampled by a given sensor will be phase related to the same signal sampled by any other sensor in the same array.

†In some cases, it is easier to simulate the results of a beamformer shown on a spectrum analyzer by modeling in the frequency domain. However, in general, other constraints would make such an approach even more difficult than straight time-domain methods.

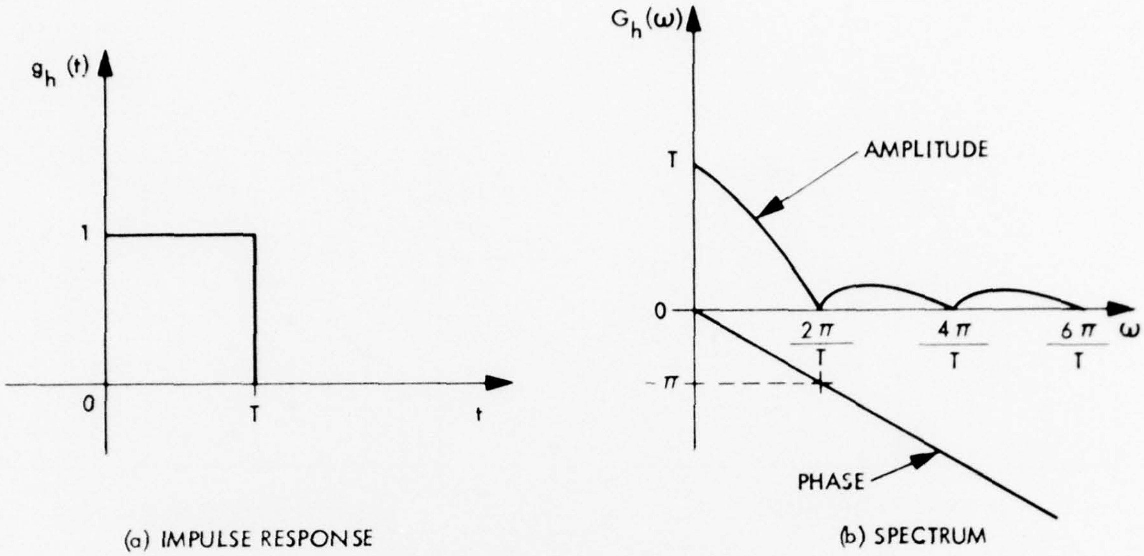


Figure 7. Characteristics of the Zero-Order Hold Interpolator

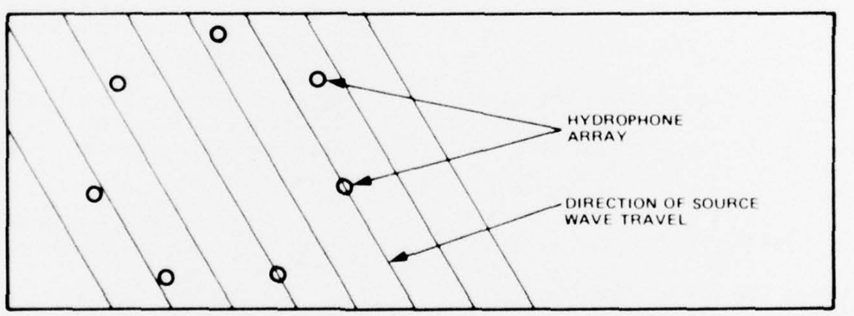


Figure 8. An Acoustic Wavefront Sweeping Past a Circular Array of Hydrophones

In a simulation, suppose a signal sampled with period T is used as the source to drive a sensor array. Let the ith array element be physically located such that at each simulation system clock time, the true value of the signal it should be sampling lies between successive samples available from the sampled signal source. As shown in Figure 9, let the relative time location of the sample required by the ith array element occur after a delay of δ_i, where $0 \leq \delta_i \leq T$, following the last known digital source signal that had passed the ith array element. Also suppose the signal value actually received by the ith sensor to be approximated by linearly interpolating between the two source signal samples that sandwich it, viz, A and C in Figure 9. Finally, the operation assumes the delay δ_i for the ith array element is constant for a given target signal arriving from a given spatial direction.

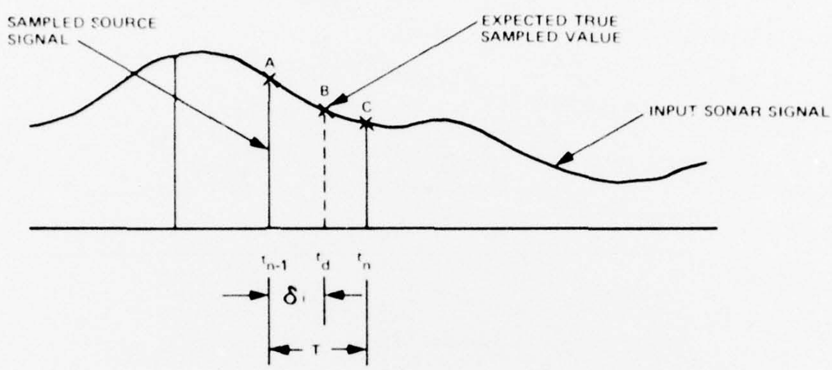


Figure 9. Signal Sampling

A = last source signal sample that passed ith array element

B = expected signal sample location by ith array element at system sample time

C = next source signal sample that will pass over ith array element

The problem is to analyze the amplitude and phase error that is introduced when the stimulating signal is derived in this manner.

ANALYSIS

Mathematical Description of Approximation Process

Let $p(t)$ be the sampling function with period T and finite sampling window λ.

If the $f(t)$ is the original signal that is to be simulated, then the sampled version of this signal source $f^*(t)$ is written

$$f^*(t) = f(t) \cdot p(t) \tag{8}$$

Since $p(t)$ is a periodic function, it can be expanded into an exponential Fourier Series.

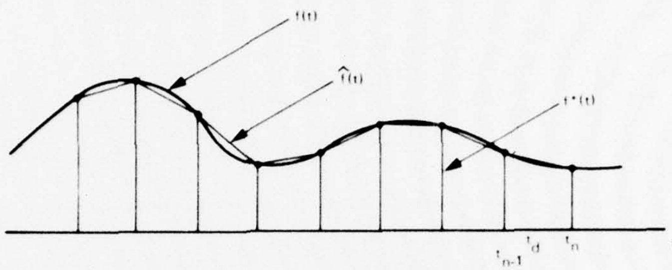
$$p(t) = \sum_{k=-\infty}^{\infty} C_k \, e^{j2\pi kt/T} \tag{9}$$

where C_k is the kth Fourier series coefficient.

Substituting Equation (9) into Equation (8) gives

$$f^*(t) = \sum_{k=-\infty}^{\infty} C_k (f(t)\exp(j2\pi kt/T) \tag{10}$$

This equation is the time domain description of the signal $f^*(t)$ which results from uniformly sampling the original continuous signal $f(t)$ by the periodic sampling function $p(t)$.



f(t) = original source signal

$\hat{f}(t)$ = sampled source signal

$f^*(t)$ = linear approximation of source signal

Figure 10. Linear Approximation of Source Signal

Suppose function h(t) is generated by linearly interpolating between successive values of $f^*(t)$. The approximate value of the signal received by the ith sensor, $S_i(t)$, on the other hand, is derived by taking the value of h(t) at time t_d, where the delay $(t_d - t_{n-1})$ from the past value $f^*(t_{n-1})$ is δ_i. At time t_d, function h(t) is written

$$h(t_d) = \left[\frac{f^*(t_n) - f^*(t_{n-1})}{T}\right] \cdot (t_d - t_{n-1})$$

$$+ \; f^*(t_{n-1}) \qquad (11)$$

Equation (11) can be rewritten to derive the sampled function $h^*_i(t)$ by appropriately time shifting $f^*(t)$ to give

$$h^*_i(t) = \left[f^*(t+T-\delta_i) - f^*(t-\delta_i)\right] \cdot \delta_i/T$$

$$+ \; f^*(t - \delta_i) \qquad (12)$$

T and δ_i are constants. Equation (12) assumes a steady state condition.

In order to assess the magnitude of the additional amplitude and phase error that is introduced into the reconstructed signal when $h^*(t)$ is used in the place of $f^*(t)$, we need to derive the spectrum of both functions in terms of the spectrum of the original signal f(t).

A Derivation of the Spectrum of $f^*(t)$ & $h^*(t)$ as a Function of the Spectrum of f(t)

Let $F(\omega)$ be the Fourier transform of f(t) and $F^*(\omega)$ the Fourier transform of $f^*(t)$. Then by the frequency shifting theorem

$$\left[e^{j\gamma t} f(t)\right] = F(\omega - \gamma) \qquad (13)$$

Equation (10) becomes, in the Fourier transform domain,

$$F^*(\omega) = \sum_{k=-\infty}^{\infty} C_k F(\omega - 2\pi k/T) \qquad (14)$$

Equation (14) relates the spectrum of $f^*(t)$ to that of f(t).

If $H^*_i(\omega)$ is the Fourier transform of $H^*_i(t)$, then by the time shift theorem,

$$\mathcal{F}[f^*(t - t_o)] = F(\omega)e^{-jt_o\omega} \qquad (15)$$

we get from Equation (14) the relationship between the Fourier transform of $h^*_I(t)$ and the Fourier transform of f(t) to be

$$H_i^*(\omega) = \sum_{k=-\infty}^{\infty} C_k \Big\{ F(\omega - \frac{2\pi k}{T}) e^{-j\omega\delta_i} + \frac{\delta_i}{T} F(\omega - \frac{2\pi k}{T}) (e^{-j\omega(\delta_i - T)} - e^{-j\omega\delta_i}) \Big\} \quad (16)$$

Note that $H_i^*(\omega) = F^*(\omega)$ for $\delta_i = \{0, T\}$

Rewriting Equation (16) yields

$$H_i^*(\omega) = \sum_{k=-\infty}^{\infty} C_k \cdot F(\omega - \frac{2\pi k}{T}) \left[(1 - \frac{\delta_i}{T}) e^{-j\omega\delta_i} + \frac{\delta_i}{T} e^{-j\omega(\delta_i - T)} \right] \quad (17)$$

Which further reduces to

$$H_i^*(\omega) = \left[\sum_{k=-\infty}^{\infty} C_k \cdot F(\omega - \frac{2\pi k}{T}) \right] \cdot A(\omega) e^{-j\phi(\omega)} \quad (18)$$

where $A(\omega)$ and $\phi(\omega)$ are the amplitude and phase modifications to the spectrum of the original sampled source signal caused by the approximation used to generate $h^*(t)$.

The relative amplitude error introduced is $|1 - A(\omega)|$ while the phase error introduced is $\phi(\omega)$.

By comparing the spectrum $H^*(\omega)$ given by Equation (17) to that of the initially sampled function $f^*(t)$, viz,

$$F^*(\omega) = \sum_{k=-\infty}^{\infty} C_k F(\omega - 2\pi k/T) \quad (19)$$

we get the spectral error function

$$\epsilon_i(\omega) = (1 - \frac{\delta_i}{T}) e^{-j\omega\delta_i} + \frac{\delta_i}{T} e^{-j\omega(\delta_i - T)} \quad (20)$$

Converting the error function in Equation (20) into the amplitude and phase format, and then simplifying, yields the amplitude and phase error as a function of the resampling delay δ and the frequency ω. Figure 11 shows the typical amplitude and phase error variations as a function of δ in the range $[0, T]$, where T is the period of the master sampling function $p(t)$.

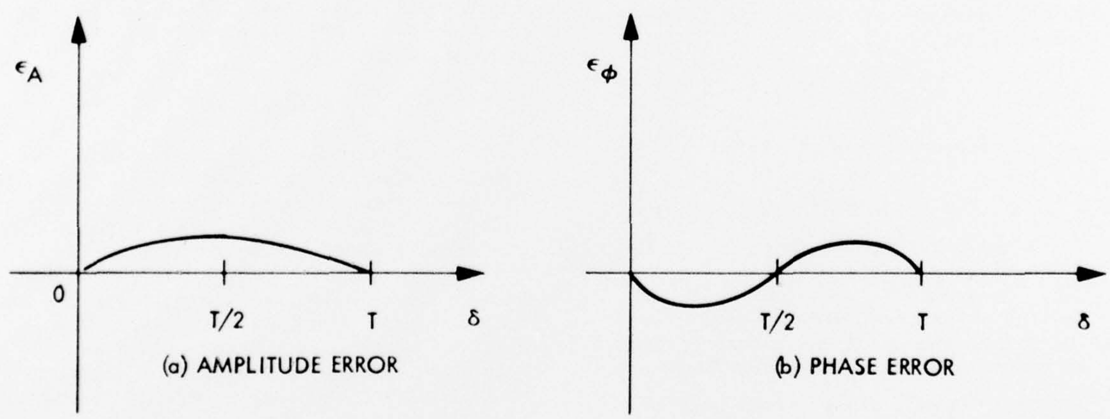


Figure 11. Error Variation as a Function of δ

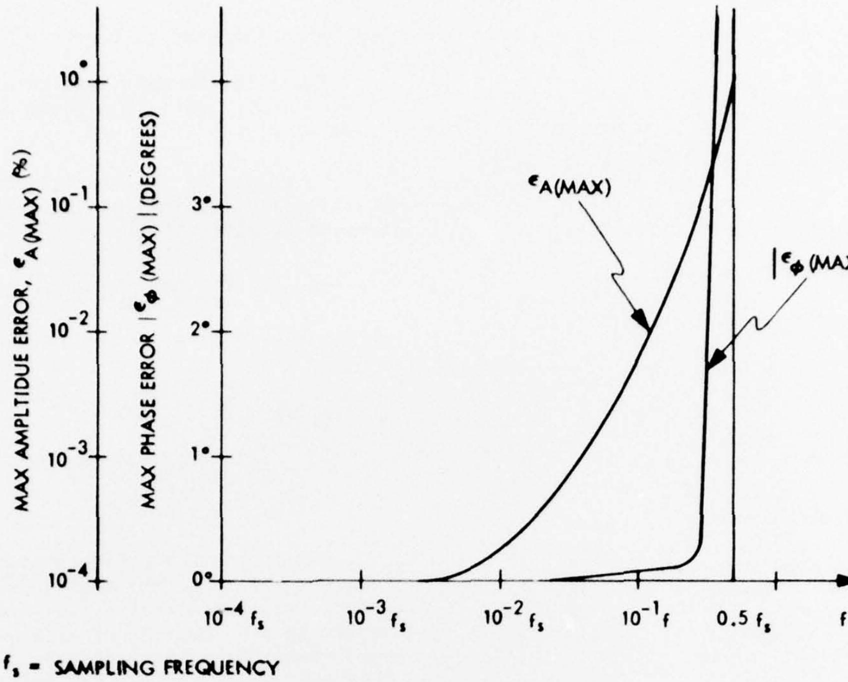


Figure 12. Maximum Amplitude and Maximum Phase Error

Solving for the maximum amplitude error $\epsilon_A(max)$ and the maximum phase error $\epsilon_\phi(max)$ in terms of frequency ω, we get the following simple expressions:

$$\epsilon_A(max) = 1-\sqrt{0.5\,[1 + Cos(2\pi X)]} \qquad (21)$$

$$\epsilon_\phi(max) = \arctan\ [-\tan^3(\pi X/2)] \qquad (22)$$

where $X \leq \frac{1}{2}$ is the ratio of the signal frequency ω to the sampling frequency ω_s. The results are plotted in the graph in Figure 12. As expected, both the amplitude error and the phase error drop to negligible values as the frequency of the signal becomes small in comparison to the sampling frequency.

To form a "beam", signals from each of the hydrophones $\{h_j\}$ in the array are delayed by time Δ_i multiplied by a prescribed weight w_j and summed together to give the composite result

$$s(t) = \sum_{j=1}^{n} w_j h_j (t+\Delta_i) \qquad (23)$$

If $S^*(\omega)$ denotes the Fourier transform of the sampled and linearly interpolated version of the composite hydrophone array signal $s^*(t)$, then the next error introduced by simulating the sonar signal in the prescribed manner will be

$$\epsilon_s(\omega) = \sum_{j=1}^{n} w_j \quad \epsilon_i(\omega) \qquad (24)$$

The actual values of δ_i in Equation (24) as reflected through Equation (20) are a function of the geometry of the array modeled and the relative angle of arrival of the acoustic wavefront.

CONCLUSIONS

The advantages of digital signal processing have received considerable publicity. For modern sonar simulation, it is seen that considerable analysis is possible to predict the effects of operating completely in the digital domain. This paper has chosen one example to show how such an analysis can be accomplished. The same can be achieved for a myriad of different other simulation methods which are available to the designers of real-time sonar simulators for use in training suites.

As new sonar synthesis equipment gets introduced into the fleet, and the task of proper simulation becomes increasingly difficult, a preliminary analysis of any proposed method will point out the strengths and weaknesses of each model. The results of such analyses will aid the designers in their quest to produce real-time ground-based simulation trainers that will continue to lighten the load on operational systems. In this way, such trainers will truly be a solution that will conserve our precious resources to be used in more effective applications.

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